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86th Congress, 2d Session - - - - - - House Report No. 2229

NOISE: ITS EFFECT ON MAN AND MACHINE

REPORT

OF THE

COMMITTEE ON SCIENCE AND ASTRONAUTICS

U.S. HOUSE OF REPRESENTATIVES

EIGHTY-SIXTH CONGRESS

SECOND SESSION

PURSUANT TO

H. Res. 133

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OCTOBER 13, 1960.—Committed to the Committee of the Whole House on the State of the Union and ordered to be printed

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LETTER OF TRANSMITTAL

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND ASTRONAUTICS,
Washington, D.C., October 13, 1960.

Hon. RALPH R. ROBERTS,
Clerk, U.S. House of Representatives,
Washington, D.C.

DEAR MR. CLERK: By direction of the Committee on Science and Astronautics, I submit the following report for the consideration of the 86th Congress.

OVERTON BROOKS, *Chairman.*

CONTENTS

		Page
I.	Committee interest	1
II.	Background	3
III.	Understanding noise	5
	The anatomy of noise	5
	The effects of noise	6
	Noise mechanism	6
	Noise sources	7
	Sound measuring references	7
	The decibel (db)	8
	Sound pressure level (SPL)	10
	Frequency spectrum	11
	Properties of a jet noise source	13
	Propagation of jet noise	13
	Perceived noise level (PNdb)	14
IV.	Major noise research effort in the Government	16
	NASA	16
	Air Force	16
	Navy	18
	CHABA	20
V.	Noise sources and problems	24
	Engine noise	25
	The turbojet engine	25
	The turbofan engine	28
	Large rocket and missile noise	29
	Boundary layer noise	30
	Definition	30
	Sonic fatigue	30
	Boundary layer noise and the astronaut	33
	The sonic boom	35
	The supersonic transport and shock wave noise	36
VI.	Hearing highlights	39
	Status of noise research	39
	Government-industry cooperation: a sampling of opinion	44
	A need for noise criteria	47
VII.	Conclusions	50
VIII.	Recommendations	51

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OCTOBER 13, 1960.—Committed to the Committee of the Whole House on the State of the Union and ordered to be printed

Mr. BROOKS of Louisiana, from the Committee on Science and Astronautics, submitted the following

REPORT

[Pursuant to H. Res. 133, 86th Cong.]

NOISE: ITS EFFECT ON MAN AND MACHINE

I. Committee Interest

During the 2d session of the 86th Congress, on May 17, 18, 19, 20, and 24, 1960, the Committee on Science and Astronautics of the U.S. House of Representatives held hearings on "Supersonic Air Transports." The problems of engine noise and the sonic boom phenomenon were prominent aspects of the hearings. The Honorable Overton Brooks, of Louisiana, chairman of the Committee on Science and Astronautics, was acutely aware of the current noise problems surrounding today's jet transport airplanes, rockets, and missiles. The committee realized that progress in the air transportation field and in military weapons systems is based on larger and more powerful propulsion systems.

The committee, therefore, proposed to hold open hearings in order to determine what research and development is being pursued both in Government and industry to achieve a solution. It was the feeling of the committee that the existence of the current noise problem was due in large measure to a lack of an early appreciation of the true nature and the extraordinary complexity of the problem, and the failure to give adequate emphasis and financial support to controlling the cause, as well as the effect. The committee believed that the problem should receive immediate and intensive attention, particularly in searching for a scientific solution which could result in substantially reducing high-intensity noise at its source.

Col. Roscoe Turner, world renowned aviation pioneer, and a man experienced in airport and air transportation management, was appointed a special staff consultant to the committee. Colonel Turner conducted a survey of the research effort currently underway in the United States to alleviate the noise problems of the "power age" prior to the scheduling of hearings on the subject. Talks were held with the Federal Aviation Agency, the National Aeronautics and Space Administration, the Navy, the Air Force, the National Science Foundation, Pratt & Whitney Aircraft, a division of United Aircraft Corp., Hartford, Conn., the Flight Propulsion Division, General Electric Co., Cincinnati, Ohio, Wright Air Development Division, Dayton, Ohio, Langley Laboratories, Langley, Va., the aviation department, Port of New York Authority, and representatives of Idlewild International Airport.

61765—60——2

Three days of hearings were scheduled for August 23, 24, and 25, 1960, and testimony was received from the following distinguished individuals:

Tuesday, August 23, 1960:

Ira Abbott, Director, Office of Advanced Research Programs, National Aeronautics and Space Administration

Dr. Richard H. Bolt, Associate Director (Research), National Science Foundation, Washington, D.C.

Dr. Laymon N. Miller, senior engineering consultant, Bolt Beranek & Newman, Inc., Cambridge, Mass.

Dr. Karl D. Kryter, supervisory engineering psychologist, Bolt Beranek & Newman, Inc., Cambridge, Mass.

Wednesday, August 24, 1960:

Dr. Richard Trumbull, Head, Physiological Psychology Branch, Office of Naval Research, Washington, D.C.

Dr. Horace O. Parrack, Coordinator of Noise and Vibration Control, Wright Air Development Division, Wright-Patterson Air Force Base, Dayton, Ohio.

Thursday, August 25, 1960:

Bernard A. Schmickrath, engineering manager, Pratt & Whitney Division, United Aircraft Corp., Hartford, Conn.

Gen. Elwood R. Quesada, Administrator, Federal Aviation Agency, Washington, D.C.

Bartholomew Spano, director, Polysonics, Inc., Washington, D.C.

Since time was a limiting factor, it was impossible to hear all interested agencies, industrial concerns and investigators in the field. The committee therefore invited selected persons to contribute their written remarks for the record. These were:

Dr. Hallowell Davis, director, Central Institute for the Deaf, St. Louis, Mo.

J. V. Naish, president, Convair Division, General Dynamics Corp., San Diego, Calif.

George M. Bunker, chairman, board of directors, The Martin Co., Baltimore, Md.

Donald W. Douglas, Jr., president, Douglas Aircraft Co., Inc., Santa Monica, Calif.

J. W. Crosby, president, Thiokol Chemical Corp., Bristol, Pa.

Courtlandt S. Gross, president, Lockheed Aircraft Corp., Burbank, Calif.

F. O. Detweiler, president, Chance Vought Aircraft, Inc., Dallas, Tex.

LeRoy Grumman, chairman, board of directors, Grumman Aircraft Engineering Corp., Bethpage, Long Island, N.Y.

Stuart G. Tipton, president, Air Transport Association of America, Washington, D.C.

William M. Allen, president, Boeing Airplane Co., Seattle, Wash.

Dan A. Kimball, president, Aerojet General Corp., Washington, D.C.

J. B. Montgomery, general manager, Flight Propulsion Division, General Electric Co., Cincinnati, Ohio.

J. S. McDonnell, president, McDonnell Aircraft Corp., Lambert Field, Mo.

J. L. Atwood, president, North American Aviation, Inc., Los Angeles International Airport, Los Angeles, Calif.

II. Background

To primitive man, noise was a prelude to danger. Loud noises created fear in man and it has been recorded throughout history that man has used noise to his psychological advantage in battle. The first detailed account is the Biblical story which is familiar to all: "So the people shouted when the priests blew with the trumpets: and it came to pass when the people heard the sound of the trumpet, and the people shouted with a great shout, that the wall fell down flat, so that the people went up into the city, every man straight before him and they took the city." (*Joshua*, Jericho is Taken.)

In more modern times noise has been used to advantage to lower the resistance of an enemy. One of the most novel was the one devised by Navy "Black Cat" patrol planes during the Solomon Islands campaign of World War II. In order to harass the Japanese, these PBY patrol aircraft dropped empty beer bottles throughout the night. The bottles would create high-pitched whistles which sounded like all the banshees of hell descending. One does not have to be too imaginative to recognize that sleep under these conditions is difficult.

It is not news to the average citizen today that noise problems are increasing. In the technological age we live in, noise is a byproduct of man's desire to move faster on the ground, in the air, and on the sea. There are more automobiles on the road than ever before—primarily due to the mass exodus from city to suburb, an increase in population and the standard of living. The propeller-driven airplane is rapidly being supplanted by turbojets, and air travel is continually on the upswing. Powerboating has become increasingly popular in the past few years and it is rarely possible to retreat to a quiet lake for rest and relaxation.

Howard C. Hardy, writing in the January 1955 issue of "Noise Control," a publication of the Acoustical Society of America, pointed out that New York City carried out the pilot study of city noises in 1929. In that year, a group of citizens banded together and started what can historically be called the first campaign against city noise. Through this effort, there was established a noise commission to make a study of the problem. The report of this commission, entitled "City Noise," was published in 1931. According to Mr. Hardy, the technical group in 1929 spent a great deal of time on automobile horns. Hardly anyone today considers the automobile horn a major source of annoyance under ordinary circumstances.

It was also in 1929 that the first portable sound-level meter, originally called a noise meter, was born. The impetus behind the development of the sound-level meter was the requirement to measure sound and noise levels outdoors for the production of "talking pictures," which moviemakers were pioneering at that time.

Aviation noise was a problem to the early aviators before it became a recognizable problem to the average citizen on the ground. The venerable speed flyers of the twenties and thirties who sat behind the powerful reciprocating engines of that day in open cockpits soon found that they were being deafened. Not only was the noise of the

engine a problem to them, but the boundary layer noise created about their exposed head and shoulders at speeds of 300 miles per hour was of equal magnitude.

Col. Roscoe Turner, only three-time winner of the Thompson Trophy Race, relates how he tried to solve the problem by first using cotton in his ears. Finding this unsatisfactory, he began to experiment with sewing ladies' powder puffs into his cloth helmet. The use of cotton and puffs of a more sophisticated design was still standard for military pilots during World War II. It was not until the introduction of military jet aircraft that serious engineering research was applied to protecting the pilot's head and hearing.

Today we find the situation somewhat reversed. The citizens who live within a 5-mile radius of the modern jet age air terminal feel that perhaps they should be wearing the cotton in their ears. They are almost as unprotected from the compressor whine of the powerful jets passing overhead at low approach altitude as the aviator of the open cockpit era (although the exposure is not continuous). Over 10 years ago, Newark Airport was dramatically closed by complaints of a fearful and hostile community. Ever since then aviation authorities have been concerned about the impact of community reactions to aviation operations. This concern has increased manyfold since the introduction of the larger more powerful multijet engine airliner. The recent and rapid increase in the amount of noise produced by jet aircraft has created medical, operational, legal, and community relations problems of the most serious nature.

FIGURE 1

NASA
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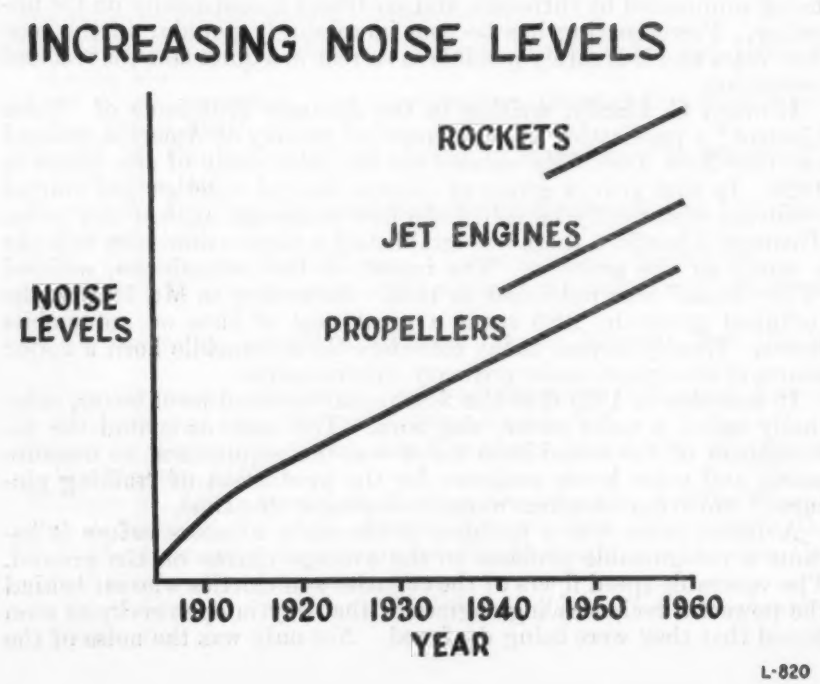

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Figure 1 illustrates graphically the noise level increase through the years. Looking into the future, it is not too difficult to visualize problems of equal magnitude with regard to people who live in the vicinity of fixed ICBM bases. A need could arise to static test fire a sampling of Atlas or Titan missiles as a gage of reliability and an indication of readiness probability. Although the frequency of such tests will not be great, the sound pressure levels will be of large magnitude. For example, the noise generated by rocket engines in terms of the spread of noise to neighboring areas could complicate community relations. A rocket engine with a thrust of 130,000 pounds will produce sound levels of 145 decibels at a distance of 100 feet, and the noise will exceed a speech interference level of 60 decibels up to 5 miles distance. These levels will not be greatly exceeded by larger rocket engines, primarily because the pressures already are exceeding the linear limits of air as a transmission medium.[1] The spread of noise is further complicated by local weather conditions and is discussed in more detail in the body of this report.

III. Understanding Noise

The purpose of this section of the report is to explain, for the most part in nontechnical terms, the anatomy of noise and to define some of the technical terms commonly used to determine the makeup and measurement of noise.

THE ANATOMY OF NOISE

Noise has two aspects. Taken one way, noise is something you sense, something you feel inside like a headache. You can hear noise, recognize it as a low-pitched rumble or a high-pitched whine such as one would hear from a turbojet engine. Taken another way, noise is a form of energy in the air, invisible vibrations that can enter your ear and make you "hear something." Noise can be defined as any unwanted sound and although this definition seems very elementary, it is remarkably sensible. It combines both aspects of noise: The sound outside of you and the feeling inside of you.[2] This letter to the editor illustrates the fact that one man's music is another man's noise:

Are Church Chimes Noise?[3]

A few years ago a church in one of our neighborhoods changed from a mechanical clock (which rang the hour and the half-hour) to an electronic chime system which rings the Westminster Chimes on the quarter-hour from 8 a.m. to 9 p.m. and plays hymns at noon and 6 p.m. There was considerable heated argument which appeared in the form of letters to the editor in the local newspaper and a protest meeting in the city hall. The protests got nowhere since it was held that churches and bells have been synonymous from time immemorial. On the other hand, the opponents claimed that electronic amplifiers are not bells and have no established religious tradition. I believe that in the end the level of the chimes was toned down somewhat, and the majority of neighbors seem to have become accustomed to them. Nevertheless, some extremists moved or threatened to move from the neighborhood. Others like the chimes and feel that the community has been benefited by them.

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[1] U. K. Ingard, a member of Working Group 33, reporting to the sixth annual meeting of the Armed Forces—NRC Committee on Hearing and Bio-Acoustics (CHABA), October 1958.

[2] Air Force Pamphlet No. 32–2–1.

[3] Letters to the editor, "Noise Control," a publication of the Acoustical Society of America.

I relate this incident since it may be of interest to people who are working on the problem of noise in suburban communities. This is a very delicate problem which should be handled with care so as not to offend anyone. However, it would seem to me that some data regarding similar problems might be useful to suburban communities, to churches, and to chimemakers.

B. B. BAUER.

OAK PARK, *August 19, 1954.*

THE EFFECTS OF NOISE

To understand why some sounds may be classified as noise, one must understand what noise can do to people. The effects of noise may include the following in descending order of severity:

1. Permanent damage to hearing mechanism.
2. Temporary damage to hearing mechanism.
3. Other bodily effects detrimental to health and safety.
4. Disturbance of sleep or rest.
5. Interference with conversation or with listening to radio or television.
6. General annoyance or irritation.

Noise does not have to be loud to cause unpleasant psychological reactions. Even a faint sound, if unfamiliar, can cause fear. Relatively low levels of noise can annoy and disrupt sleep. A mosquito buzzing about the bedroom at night is a familiar example. On the other hand, high noise levels can interfere with job performance. Annoyance and fear reactions are influenced by association with past disturbances, as well as by the immediate noise.

Speech interference can be defined as the masking of desired sounds by undesired noise. It can only be caused by noise occurring at the same time as the speech itself and the degree of interference caused may vary from only a small annoying amount to nearly complete interference and a total breakdown of communications.

Loss of hearing is the most common of the physiological effects of noise. Treatment of hearing loss depends on the noise intensity, the duration of exposure, the susceptibility of the individuals to hearing loss and other factors. It can vary from slight impairment at high frequencies only, to substantial hearing loss at all frequencies. Usually, noise-induced hearing loss is temporary, lasting only a few hours or days at most. However, continued exposure can result in permanent impairment. Other physiological effects such as pain, nausea, and bleeding of the ears can only be caused by exposure to extremely intensive noise fields.

NOISE MECHANISM

Every noise problem breaks down into three component parts:

A source radiating sound energy.
A path along which sound energy travels.
A receiver such as the human ear.

The control of noise at the source is an engineering problem to be solved by modifying or redesigning the source itself. The design of the compressor section of a jet engine to raise the frequency of the compressor whine out of the audible range of the human ear would be one example.

Noise reduction along the path can be accomplished in several ways: by shielding or enclosing the source, by changing the orientation of the source, by using a suppressor such as that in current use on today's jet transport engines, or by shielding or enclosing the receiver. Personnel working in close proximity to jet engines, guided missiles and rockets must be protected by ear plugs and ear muffs.

NOISE SOURCES

Sounds are caused by disturbances in the air. An astronaut traveling the vast reaches of outer space would not receive any sound originating from outside his vehicle simply because there is no air surrounding his spacecraft. Any movement of air such as that caused by rotating propellers, jet engine exhaust streams, or vibrating equipment creates sound. For the most part, this is unwanted sound (noise). Common sources of noise which plague modern man today include the following:

1. Jet airliners and military aircraft taking off or landing.
2. Rocket and missile static test firing and takeoff.
3. Jet airplanes undergoing maintenance runup on the ground.
4. Jet engine test-stand operations.
5. Traffic, machinery, and people.

SOUND MEASURING REFERENCES

In order to describe noise sources for comparative purposes and to measure them numerically, noise sources can be characterized as follows:

1. The total acoustic power of the source measured in watts.
2. The distribution in space of the acoustic power radiated by the source.
3. The frequency spectrum or tone quality which indicates the amount of acoustic power of the source in each of several frequency bands.

The strength of a sound source is its total acoustic power in watts. While this total power is difficult to measure, it is not too difficult to measure the pressure changes in air, which are caused by the source, by strategically taking measurements with sound-level meters in the sound field. The variations in the air pressure are measured and recorded as sound pressure level (SPL) existing at a definite position relative to the source. By measuring pressure levels at a number of calculated positions for each of two sources of sound, a comparison of their strengths can be determined without having to measure the total acoustic power being radiated.

THE DECIBEL (DB) [4]

The extent of variation in pressure is measured in terms of a unit called the microbar, which is a pressure on one dyne per square centimeter or approximately one-millionth of the normal atmospheric pressure (standard atmospheric pressure=1,013,250 microbars). This unit is not often mentioned in giving the results of a noise measurement, but it is usually implied when the more common term, the decibel (db), is used.

Although to many laymen the decibel is uniquely associated with noise measurements, it is a term borrowed from electrical communication engineering, and it represents a relative quantity. When it is used to express noise level, a reference level is implied. Usually, this reference level is a sound pressure of 0.0002 microbar which is normally referred to as "0 decibels." This is the starting point of the scale of noise levels. This starting point is about the level of the weakest sound that can be heard by a person with very good hearing in an extremely quiet location. Other typical points on the scale are shown in figures 2 and 3. The sound level in a large business office usually is between 60 and 70 decibels. Among the very loud sounds are those produced by large jet engines, subways, and riveting machines which are in the range of 100 or more decibels. These typical values provide a feel for the term "decibel," as applied to sound level. From a strictly technical point of view, the decibel is a logarithmic ratio of two values of power, and equal changes in decibels represent equal ratios. Thus, a change of 6 decibels represents a change of 4 to 1 in power.

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[4] "Handbook of Noise Measurement," General Radio Co.

FIGURE 2

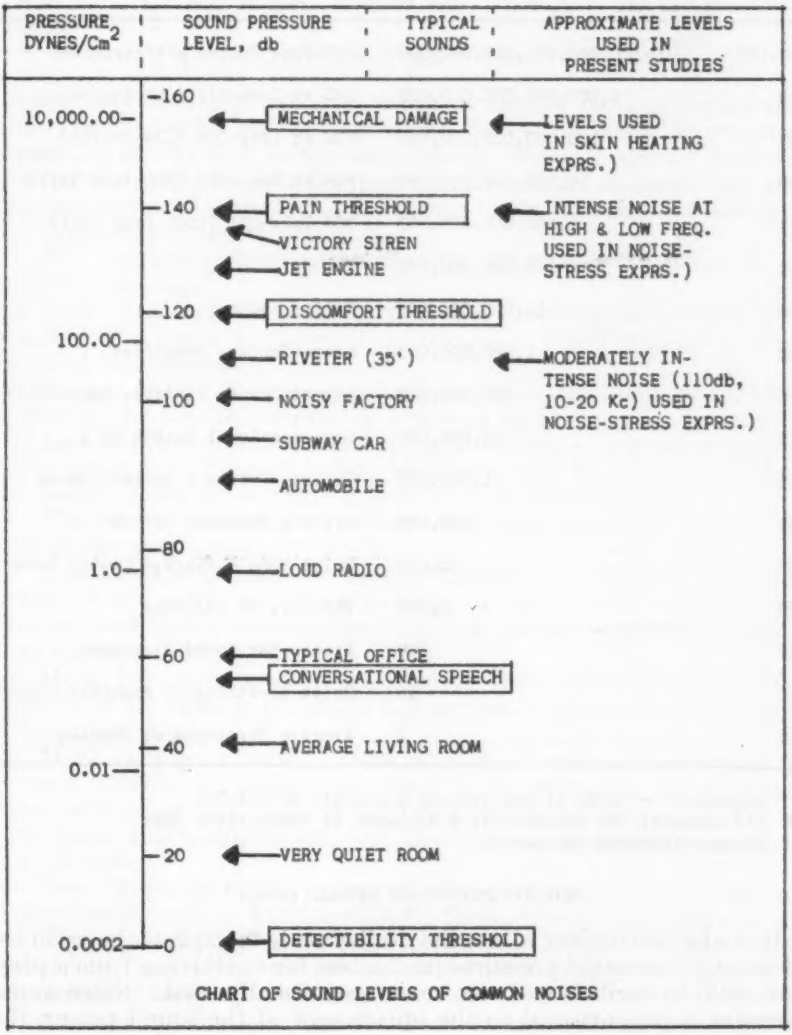

CHART OF SOUND LEVELS OF COMMON NOISES

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FIGURE 3

Relative Intensities of Various Common Sounds Expressed in Terms of Decibels and in Terms of Their Absolute Relationship

DECIBELS	DEGREE OF NOISE INTENSITY*	SOURCE OR TYPE OF NOISE**
160-170	10-100,000,000,000,000,000	J57-Type Engine w/Afterburner
150	1,000,000,000,000,000	A4D at Take-Off (J65 Engine)
140	100,000,000,000,000	F3D at Take-Off (J34 Engine)
130	10,000,000,000,000	F84 at Take-Off (80' from Tail)
120	1,000,000,000,000	DC7 Take-Off (150' from Tail)
110	100,000,000,000	Thunder
100	10,000,000,000	Boiler Factory
90	1,000,000,000	Large Truck - Unmuffled
80	100,000,000	Street Corner Traffic, Large City
70	10,000,000	Conversational Speech (3')
60	1,000,000	Typical Office - Ambient Noise
50	100,000	Private Business Office
40	10,000	Quiet Home - Average Living Room
30	1,000	Theatre, No Audience
20	100	Studio for Sound Pictures
10	10	Quiet Breathing in Anechoic Chamber
0	1	Average Threshold of Hearing

* Expressed in terms of the average threshold of hearing
** All examples are computed at a distance of twenty-five feet unless otherwise indicated

SOUND PRESSURE LEVEL (SPL) [5]

It is also convenient to use the decibel scale to express the ratio between any two sound pressures; and tables for converting from a pressure ratio to decibels and vice versa are normally used. Since sound pressure is proportional to the square root of the sound power, the sound power ratio for a given number of decibels is the square root of the corresponding power ratio. For example, if one sound pressure is twice another, the number of decibels is 6; if one sound pressure is 100 times another, the number is 40 decibels.

[5] ATC Manual 86-1, "Jet Noise."

The sound pressure level can also be expressed as a sound pressure level with respect to a reference sound pressure. For airborne sounds, this reference sound pressure is generally 0.0002 microbar. Then the definition of sound pressure level (SPL) is numerically expressed:

$$SPL = 20 \log \frac{P}{0.002} db \; re \; 0.0002 \text{ microbar}$$

Where P is the root-mean-square sound pressure for the sound in question.

FREQUENCY SPECTRUM

Noise may be considered as continuous narrow-band or wide-band sound; or it may be intermittent sound, including single or repeated impacts or shocks such as the sonic boom. Noise frequency analysis gives substantial clues as to the most effective means of controlling and reducing noise. In brief, the following is a comparison of low and high frequency noises of interest:

1. The frequency distribution of noise determines the character or quality of the noise.
2. Low frequency noise is heard as the rumbling of thunder, the sounding of a foghorn, the rattling of windows, and the roar of a jet engine at takeoff power.
3. A typical high frequency noise is heard as the hissing of a compressor air jet or the compressor whine of an idling turbojet engine.
4. Low frequency noise contains high energy, a long wave length, and is not radiated directionally, whereas a high frequency noise has low energy, short wave length and is radiated directionally.
5. The energy contained in sound and noise decreases rapidly as frequencies increase.
6. Low frequency noises are readily transmitted over long distances through solid materials, often to large surfaces, such as buildings, capable of radiating them noisily. Anyone having experienced a sonic boom can attest to this fact.
7. High frequency noise is less readily transmitted through solid objects and its effect is generally felt as direct radiation or reflection of direct radiation.
8. High frequency noise is more readily controlled by interposing barriers between its source and areas to be protected. This is one reason why noise complaints in residential areas decrease in the winter when doors and windows are shut and increase in the summer when they are open.
9. Low frequency noise is best controlled by providing a discontinuity in the path of its transmission through solid material such as insulation and cushioning material in building design. It might well be that building codes should be revised to acknowledge the increase in noise levels of modern-day living.

There are eight frequency bands which are generally used to describe the frequency characteristics of jet engine noise expressed in cycles per second (c.p.s.). These are: 20–75 c.p.s.; 75–150 c.p.s.; 150–300 c.p.s.; 300–600 c.p.s.; 600–1,200 c.p.s.; 1,200-2,400 c.p.s.; 2,400–4,800 c.p.s.; and 4,800–10,000 c.p.s. Figure 4 is a graphic illustration.

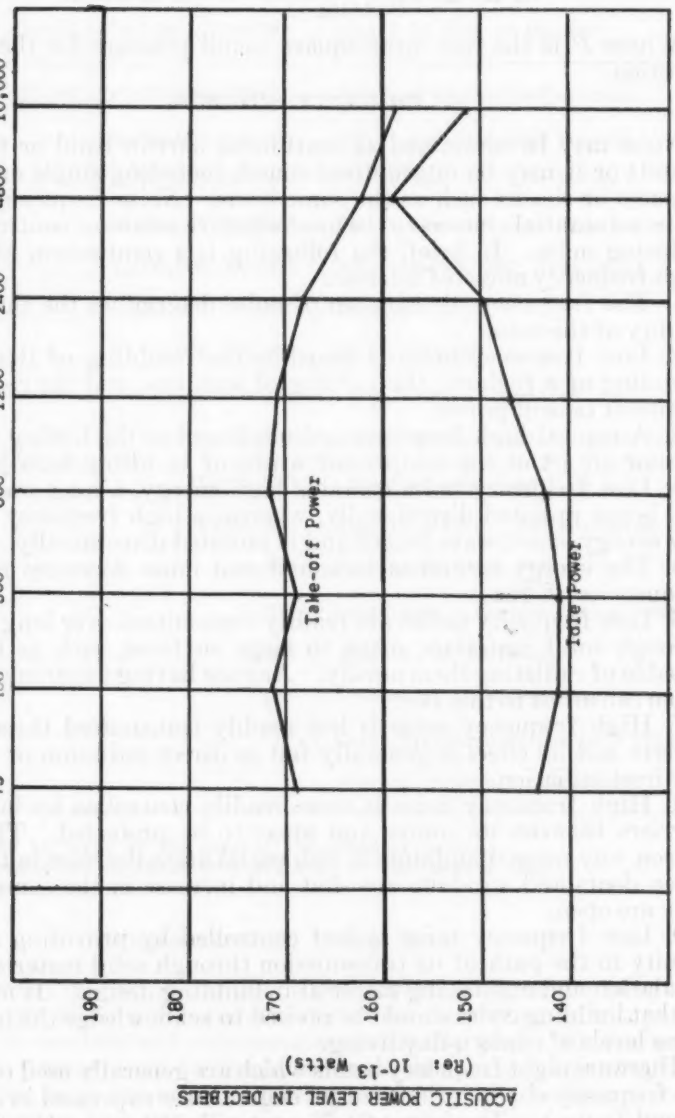


Fig. 4 -- Acoustic Power Spectra for a Typical Turbojet Engine

For practical purposes, typical low frequency noise can be considered in the range between 20 c.p.s. and 1,000 c.p.s. Approximately 1,000 c.p.s. and above is considered the region of high frequency, and is generally annoying and more hazardous to human hearing. Figure 4 illustrates the comparison between two operating conditions of a powerful turbojet engine. It can be seen that at takeoff power the acoustic power level measured at the engine is very high at all frequency bands. At the idle or low power engine operation, the acoustic power level across the frequency spectrum is much lower at the low end of the spectrum, but almost approaches the same point on the high power curve in the 2,400–4,800 c.p.s. band. This is the characteristic compressor whine which is heard during the low approach to landing and taxiing the airplane to and from the loading ramp.

PROPERTIES OF A JET NOISE SOURCE [6]

A jet noise source can be described by specifying its total acoustic power radiated, distribution of this power with respect to frequency and directivity, or the distribution of this power in the atmosphere. These three acoustic variables in turn depend on the type of engine and the operating conditions since the acoustic power varies from one jet engine to another depending upon the thrust delivered. For turbojet engines, the total noise power can be related to a computed quantity that takes into account the total mass flow of air and fuel through the engine, jet velocity exit, the temperatures at jet exits and the diameter of the tailpipe exit. These data are required in graphic form in order to evaluate what the noise problem will be at an airport or engine test facility.

Most jet engines produce a characteristic pattern of noise directivity. When a jet airplane engine is idling, the predominant noise is radiated from the compressor at the front of the engine intake. As the power setting is increased, the compressor noise is overshadowed by the jet exhaust. This occurs even though the compressor noise has actually increased at the same time. The shift in noise level in the frequency spectrum is also accompanied by a shift from the front of the aircraft to the 120° to 140° region as the power setting increases toward maximum takeoff power.

PROPAGATION OF JET NOISE [7]

Some of the factors which influence noise level during propagation are:

1. Distance: The spreading and dissipation of energy, and the inverse square law.
2. Atmosphere: Molecular absorption, temperature gradient, wind gradient, and shadow zones.
3. Terrain: Shielding and diffraction by foliage and ground buildings; effects depend on frequency.

Noise radiating from a source spreads out over an increasingly larger area as it travels from its source. Because of this "spreading," the energy strength is "thinned out." Noise reduction due to the

[6] ATC Manual 86–1, "Jet Noise."
[7] ATC Manual 86–1, "Jet Noise."

inverse square law is equal to 6 decibels for each doubling of the distance. Also, atmospheric effects must be considered. There is a continuous reduction in noise energy level due to absorption in the air, to bending refractions, and scattering of noise due to air turbulence.

Absorption of noise energy in the air is due to the viscosity of the air and the amount of water vapor in the atmosphere. Humidity has an important effect on noise level. Attenuation of noise due to humidity increases with the frequency of noise. For example, at 50 percent relative humidity, the attenuation at 1,500 c.p.s. is about 0.3 decibel per 100 feet, while at 6,000 c.p.s., it is about 2 decibels per 100 feet, or over six times as great.

In air the velocity of sound is proportional to the square root of the absolute temperature. If the temperature is constant, then the velocity of sound will be the same at all points in the air, and a sound wave traveling away from a noise source will be undistorted. However, if the air temperature varies from point to point, sound waves will flow in curved paths, bent in the direction away from higher temperatures and toward the lower temperatures.

If the temperature of the atmosphere decreased with height above the ground, as on a hot summer day, it could be expected that sound waves would be bent away from the ground. This bending of the sound results in the formation of a shadow zone in which noise levels of the source are very much reduced. At night and during the winter, there is generally an inversion of the temperature gradient and the sound waves are bent downward. This accounts for the reason noise appears to be much louder on calm, cool, clear nights than in the daytime. (This also depends upon the level of background noise as well.)

Further irregularities are introduced by the existence of wind gradients. The velocity of sound is materially changed in a moving medium. Since wind velocity varies with height, refraction effects similar to those caused by temperature gradients will be present. Consequently, sound will bend away from regions of high velocity and toward regions of lower velocity. When both wind velocity and temperature gradients exist, it is possible for them to produce canceling or intensifying acoustic effects depending upon the conditions.

Terrain and buildings also play a part in sound propagation. As sound passes over the Earth it is absorbed to some extent by vegetation and soil. These effects are more pronounced as the height and thickness of vegetation increases. Buildings, tall trees, and other obstacles can block the sound or reflect it out of its original path. This phenomenon is known as shielding and is more noticeable at high frequencies than at low frequencies.

PERCEIVED NOISE LEVEL (PNdb)[8]

Although the measurement of human reactions is a complex problem, some orderly relations between the readings recorded from physical instruments and the feelings people experience when they are exposed to sound have been established. One such relation developed

[8] Excerpts from an article entitled, "Reaction of People to Exterior Aircraft Noise," published in Noise Control, September 1959—Leo L. Beranek, Karl D. Kryter, Laymon N. Miller, of Bolt Beranek & Newman, Inc.

is the perceived noise level in units of PNdb. This quantity expresses in a compact way the measure of "noisiness" that is implicit in a listener's reaction to the sounds of aircraft, and yet it is a measure on a scale that is roughly comparable to the more familiar scales of physically measured noise levels. The PNdb is a measurement scale conceived and developed by Bolt Beranek & Newman, Inc., acoustical consultants of Cambridge, Mass.

The perceived noise level takes into account the distribution of power as a function of frequency, i.e., the frequency spectrum of a sound. In particular, the perceived noise level of a sound reflects the fact that people judge higher frequencies to be more annoying or less acceptable than lower frequencies when factors such as meaning, novelty, adaptation, etc., are held constant. The method of computing perceived noise level follows the concepts and structures, but not the loudness function developed by S. S. Stevens for calculating the loudness level of a complex sound.

The rating scheme using perceived noise level (in PNdb) was derived from studies in which people judged the relative annoyance value of pure tones and narrow bands of noise. The weights assigned to the various frequency components of a sound and the method of calculating PNdb are not based upon judgments made of the noise from airplanes.

However, a series of experiments were conducted in which people judged the relative acceptability of the flyover noise made by various jet- and piston-engined aircraft. The data from these judgment tests revealed that the PNdb values calculated from a knowledge of the spectra of the aircraft sounds involved tended to underestimate by a few "decibels" the relative noisiness or unacceptability of the jet aircraft. Nevertheless, the perceived noise level predicted the acceptability of the jet- and piston-aircraft noises more accurately than did other methods.

Perceived noise levels in PNdb have several useful interpretations. Suppose, for example, that a propeller airplane has a perceived noise level of 110 PNdb, and an overall sound pressure level of 105 decibels, and suppose that a turbine-driven airplane has a perceived noise level of 120 PNdb and an overall sound pressure level of 105 decibels. These numbers say that on the sound-level meter the two noises measure alike. However, when presented to listeners, the turbine-driven airplane is found to be 10 PNdb more noisy than the propeller aircraft. To be perceived equal in noisiness to the propeller-driven airplane, the overall sound pressure level (in decibels) of the turbine-driven airplane would have to be reduced by 10 decibels without changing the spectrum and duration of the noise. If this were done, the perceived noise level would drop from 120 to 110 PNdb and the overall sound pressure level would drop from 105 to 95 decibels.

The PNdb concept is not a criterion. It contains no value judgment as to the acceptability of a noise. It simply measures the human rating of noisiness and is one of the factors necessary to establish criterion for the design of quieter powerplants. Other factors would include the number and duration of the noise exposures, the time of day or night, the amount of previous exposure, and several other subtle factors.

IV. Major Noise Research Effort in the Government

NASA

The National Aeronautics and Space Administration has long been aware of the noise problems incidental to aircraft operations. As far back as 1916, the predecessor of NASA, the National Advisory Committee for Aeronautics (NACA), took official note of the problem. However, from 1916 through the 1920's, no extensive or integrated effort was really conducted because of a lack of sound measuring equipment. The 1930's saw advancements in the electronics field which enabled sound engineers to design measuring and analysis equipment to allow the NACA to conduct research on noise sources. Practically all of the early work was directed toward studying propeller noise.

After World War II, the introduction of the turbojet-powered airplane and the increase in flight speeds into the supersonic range created a whole new series of noise problems. The NASA has invested much research effort into the study of sonic fatigue and boundary layer noise on aircraft and missile structures, the sonic boom effect, the turbojet and bypass (turbofan) engine, noise suppression, and the effects of aircraft noise on the pilot, on passenger comfort, and on the general public.

With the coming of the space age, NASA has to cope with even more complicated noise research problems. The advent of powerful rockets and the dawn of manned space flight has vastly affected the orientation of the NASA noise research program.

According to testimony heard before the House Committee on Science and Astronautics, a total of 185 technical papers on the various aspects of the noise problem have been published by the NACA and NASA. In addition, NASA has augmented its inhouse research effort by contracting for basic research investigations at several universities. Research effort in terms of dollars has amounted to about $600,000 per year for the past several years and NASA is expected to sustain this level of effort in the future. The investment for facilities utilized for noise research on a time-share basis with other aeronautical and space programs (such as wind tunnels) runs into many millions of dollars.

AIR FORCE

In November 1952, the Air Research and Development Command, in recognition of the growing requirement for research data on noise and its control, created the Office of Coordinator of Noise and Vibration Control. The purpose of this Office was to draw together, at the Wright Air Development Division, the responsibility for planning, implementing, and reporting of the many noise studies then being conducted by the various branches of the Air Force. The creation of this Office occurred at the same time that the Armed Forces joined with the National Research Council in sponsoring the Committee on Hearing and Bio-Acoustics (CHABA). Dr. H. O. Parrack, who testified before the Committee on Science and Astronautics, headed this Office.

In early 1954, the Air Force assumed the sponsorship and responsibility for some noise-study work previously sponsored by NACA, which had contracted for pioneering work with the National Opinion Research Center at the University of Chicago under Dr. Borsky.[9] This study dealt with the sociological and sociopsychological problems of people in a noise environment. The Office of the Coordinator of Noise and Vibration Control provided administrative management, and the actual responsibility for the operation of the study was placed under Dr. H. E. von Gierke, head of the Bio-Acoustics Section of the Aero Medical Laboratory at WADD. It can therefore be said that the first major Federal Government study on community reaction to noise was under the sponsorship of the Air Research and Development Command at Wright Air Development Division, Dayton, Ohio. (Later work was done by the Air Force Personnel and Training Research Center (AFPTRC), Crew Research Laboratory, Randolph Air Force Base, San Antonio, Tex.) Dr. Borsky's studies revealed that community responses to aircraft noise are influenced by many variables. It was also at this time (1954–55) that study emphasis shifted from propeller to turbojet engine noise.

The Air Force also initiated a program in 1954 to study missile noise, its generation, propagation, effects, and control. This program expanded through 1957, the year maximal effort was applied.

The Air Force philosophy in attacking the noise problem was to employ a system approach. The program objectives have been to insure control of human exposure to acoustic energy and vibration, to assure levels of acoustic energy that would be acceptable to humans in a normal working or living environment, to prevent damage to structures by controlling acoustic energy levels, and to provide or develop general noise criteria for aircraft and missiles upon which to base airbase and missile site planning.

The funding history of Air Force programs in noise and bioacoustics research, development, test, and evaluation is as follows:

Funding history

[In millions]

Fiscal year	Basic and applied research	Engineering development	Total
1953	$1.25	$0.6	$1.85
1954	1.25	.6	1.85
1955	1.80	.9	2.70
1956	2.00	1.0	3.00
1957	2.00	1.0	3.00
1958	1.00	.5	1.50
1959	1.00	.5	1.50
1960	1.00	.5	1.50
1961	1.00	.5	1.50
Total	12.30	6.1	18.40

Future Air Force research effort will be directed toward:[10]

1. Detailed information about sound fields of advanced propulsion system sources, including data on the "near field" and detailed phase

[9] Résumé for the CHABA Council of the History of the Study of Community Reaction to Aircraft Noise, 1951–56.

[10] Hearings, pp. 144–145.

correlation of the sound field over large areas—a requirement for application to the sonic fatigue problem.

2. Exploration of new mechanisms of acoustic energy generation associated with nuclear propulsion systems and other exotic systems.

3. Measurement and evaluation of the effects of low-frequency reentry and blast-off sound fields and vibration.

4. Engineering developments to incorporate available research data in the design of effective ground runup suppressors.

5. A study of the long-distance propagation of low-frequency sound in relation to missile operations.

6. An evaluation of the effects on man of very low frequency sound and vibration, and the impulsive application of acoustic energy of any form.

7. A determination of the effects on man of long duration exposure to sound with emphasis on occupants of manned satellite and space vehicles.

8. An evaluation of the significance of the physiological and behavioral changes in man induced by exposure to low level noise over long periods of time.

9. An evaluation of the significant psychophysical, psychological, sociological, economic, and other factors that is the basis of adverse community response to aircraft and missile noise.

NAVY

The noise problem has been with the Navy for many years. The operational confinement, which is a characteristic of shipboard environment, makes the noise problem an acute one for the Navy. This is particularly true on board aircraft carriers operating jet aircraft because there is simply no place to go to avoid being subjected to high noise levels on the flight deck.

The first significant effort toward a research approach was conducted by the Bureau of Medicine and Surgery in 1952, when noise measurements were taken during jet aircraft operations on the flight deck of an aircraft carrier. This survey noted that noise intensities frequently reached 130 to 135 decibels and directly associated hearing loss in flight deck personnel in the area of 1,000 cycles per second. Loss of hearing in this particular frequency band impairs voice communications.

At this point in time the National Research Council Committee on Hearing became interested in the Navy problem and suggested that the Navy gather data on the subject of acoustic trauma. The Navy appointed a noise survey team, under the sponsorship of an Office of Naval Research contract with the Psychoacoustic Laboratory of Harvard University. This group visited Navy and Air Force installations, academic institutions and aircraft industrial concerns, as well as observing flight operations on board aircraft carriers. The results of this survey concluded that the noise problem was of sufficient magnitude to require action at the Department of Defense level.

At the recommendation of the Committee on Medical Sciences of the Research and Development Board, Department of Defense, and the endorsement of the National Research Council Committee on Hearing, a group of civilian and military experts organized the

Armed Forces—National Research Council Committee on Hearing and Bio-Acoustics (CHABA) at a meeting on December 15, 1952.[11]

The Navy Bureau of Aeronautics issued the first instruction allocating responsibilities for protection of personnel and improvement of communications under noise conditions in November of 1953. It was also at this point in time that early recognition of the guided missile as a serious noise source was evidenced.

During 1954 and 1955, great strides were made in the development of the earplug and ear protection devices which became standard equipment to be worn by all naval personnel whose duties required them to work in high intensity noise fields. Work on jet engine noise suppressors was also underway.

In 1956, a mobile audiometric laboratory was completed and utilized on aircraft carriers to collect audiometric data during actual flight operations. The information collected, however, did not establish the presence of significant hearing losses among the men taking part in the test. It was apparent to the investigators, however, that increases in noise intensity above the values recorded, or continued prolonged exposure at the recorded levels, could result in permanent auditory change.

Nonauditory effects were also investigated by the Navy. Utilizing deaf subjects, so as to avoid the possibility of damage to a normal hearing system, the noise level at which hemorrhage of the middle ear might be expected was determined, as well as information concerning visual disturbances which arise in a high intensity noise field.

In April of 1956, a project was established at the Naval Air Test Center, Patuxent River, Md., to provide for the measurement of engine noise profiles of the then current, as well as future, naval turbojet powered aircraft. The information resulting from this project kept medical and engineering groups informed and provided a basis for changes in operational procedures. It was also during this period that contracts were let to conduct analytical and experimental research, utilizing small-scale test models to obtain design parameters and performance analysis for inlet and exhaust noise suppressors. It is interesting to note that the inlet noise suppression problem was approached, utilizing the resonator principle which is a technique currently being exploited by engine manufacturers today in the design of turbofan engines. In theory, this type of inlet suppressor will attenuate the high frequency inlet noise inherent with turbojet compressors without appreciably affecting the overall sound pressure level.

Inflight suppression of noise without an appreciable loss of combat power proved to be most difficult for the Navy. Thus, the Navy decided to go back to the basic physics of the problem in the hope of finding a breakthrough to the secret of inflight noise suppression.

It was hoped that by going back to the laboratory and reinvestigating the fundamental factors affecting the generation of noise, such as temperature, velocity, pressure, turbulence and other phenomena, it might make it possible to obtain greater knowledge of the exact nature of noise. New avenues for the development of better techniques for solving the noise problem were urgently needed.

[11] Hearings, p. 79.

In 1959, the decision to return to basic studies in the physics of noise generation resulted in acquiring information through a contract with the General Electric Co. which conducted experimental research and tests to determine the basic mechanisms of the turbulence—sheer interaction as a factor affecting the generation of jet engine noise. Whether this type of work will result in a significant breakthrough in the near future is problematical.

Advanced type ground noise suppressor designs are currently in research and development which show promise of achieving 30 db of noise suppression. The Navy, in 1960, also issued contracts to two industrial concerns for research and development of an advanced type portable ground suppressor that acoustically treats noise generated from both the jet engine inlet and the exhaust.

The advent of the guided missile on board ships of the Navy posed much the same problem as did the jet aircraft on aircraft carriers. However, the development work on noise barriers and personnel protective equipment was directly applicable to the missile problems. Studies of this problem are conducted at the U.S. Navy Weapons Laboratory at Dahlgren, Va., where all relevant data on new missile systems are compiled.

The Pacific Missile Range provides engineering data on more powerful noise sources such as space system rocket boosters of high thrust values. At this facility the Navy is building its launching pads for the large weapon systems of tomorrow in deep ravines to take advantage of terrain attenuation. These launch complexes are also centrally located within the land area over which the Navy exercises control.

The funding history of Navy programs in noise and bioacoustics is as follows:

Funding history

[In millions]

Fiscal year	Basic and applied research	Engineering development	Total
1953	$0.050		$0.050
1954	.076		.076
1955	.330		.330
1956	.507		.507
1957	.617		.617
1958	1.242		1.242
1959	.596	$0.700	1.296
1960	1.770	.726	2.496
1961	.306		.306
Total	5.494	1.426	6.920

CHABA

The Armed Forces—National Research Council Committee on Hearing and Bio-Acoustics (CHABA) was organized on December 15, 1952. The purpose of this organization was to provide a group of informed consultants who could assist the armed services and Government agencies in acquiring answers to research questions concerning noise and its effects. CHABA consults with and advises the Armed Forces in such general areas as:[12]

[12] Sixth Annual Report of CHABA Statement of Purposes and Methods of Operation.

1. Auditory physiology, psychoacoustics and auditory standards;
2. Communications, particularly speech communications in noise;
3. The psychological and social reactions of man to noise;
4. The auditory and nonauditory effects of high intensity acoustic energy on man;
5. The means of protection against the undesirable effects of acoustic energy; and
6. The relevant physical and engineering problems of the generation, measurement, and control of acoustic energy.

CHABA activities have been supported by funds contributed equally by the Army, Navy, and Air Force. On July 1, 1960, the Federal Aviation Agency also became a supporting agency as a result of a meeting held on May 31, 1960, between executives of CHABA and the FAA. These four organizations each contribute $12,500 annually to support the work of the Committee. The secretariat and the continuing operation of the Committee have been provided by the Central Institute for the Deaf, St. Louis, Mo., under contract with the Office of Naval Research, which acts as contracting agent for the three armed services. Dr. Hallowell Davis, director of the Central Institute for the Deaf, served as the Executive Secretary of CHABA from its formation in 1952 until September of 1959. On September 1, 1959, the secretariat was transferred to Washington, D.C., under the auspices of the National Research Council. Dr. Milton Whitcomb is currently serving as Executive Secretary.

CHABA activities are planned and directed by a council composed of six to nine members. The Army, Navy, and Air Force each have a representative and the National Research Council appoints three to six members. The Council selects from its membership a chairman and a deputy chairman, also an executive secretary. The Council usually meets two or three times a year.

The full Committee on Hearing and Bio-Acoustics consists of about 120 regular members, of whom about 37 are civilians appointed by the National Research Council. The latter appointments include engineers and scientists who are qualified by training, experience, or employment in the fields of acoustics, vibration, psychology, physiology or medicine. Several Government agencies with interest in this general area appoint about 15 affiliate members to the Committee for liaison purposes. These affiliate members include the National Bureau of Standards, U.S. Atomic Energy Commission, U.S. Public Health Service (Bureau of State Services and the National Institutes of Health), the Veterans' Administration, Federal Housing Administration, National Aeronautics and Space Administration, Civil Aeronautics Board, and the Canadian Joint Staff.

The Committee meets annually, usually in October in the Washington area. The meetings are restricted to the actual CHABA membership and specially invited guests in order to preserve an intimate atmosphere of free discussion. Except for travel expenses in connection with attending meetings National Research Council members serve without financial compensation unless they are asked to serve on one of the working groups.

The major work performed by CHABA is accomplished by working groups composed of Committee members, often supplemented by invited consultants or former members. Working groups are formed to work on problems brought to the Council by representatives of the

three armed services, and since July 1, 1960, the FAA. The National Research Council members of the working groups are paid for their time spent on work in these groups and are provided travel expenses. The Council selects the membership of these groups on the basis of the fields of knowledge which should be represented in the solution to the problem. When a working group has prepared its report, the Council has the responsibility of accepting and transmitting it to the requesting agency either with or without additional comment or endorsement.

The first definitive look at the noise problem undertaken by the CHABA was known as the Benox report (Biological Effects of Noise, Exploratory). Since this first report, published in December of 1953, many pioneering papers have been written under the sponsorship of CHABA. The following is a cumulative list of the reports prepared and distributed by this Committee:

CHABA reports

1. "High Intensity Noise and Military Operations: An Evaluation," January 25, 1954, CHABA Report No. 1. Technical Report No. 1 to the Office of Naval Research from the Central Institute for the Deaf, Contract Nonr 1151 (01), NR 140–069.

2. "The Effects of Blast Phenomena on Man," by D. H. Eldredge, September 1, 1955, Report No. 3. Technical Report No. 4 to the Office of Naval Research from the Central Institute for the Deaf, Contract Nonr 1151 (01), NR 140–069.

3. "Noise and the Community," the proceedings of the second meeting of the Armed Forces National Research Council Committee on Hearing and Bio-Acoustics, a joint aeronautics Special Subcommittee on Aircraft Noise, October 25–26, 1954. October 1955, CHABA Report No. 4. Technical Report No. 5 to the Office of Naval Research from the Central Institute for the Deaf, Contract Nonr 1151 (01), NR 140–069.

4. "The Testing of Hearing in the Armed Services," the proceedings of the third annual meeting of the Armed Forces National Research Council Committee on Hearing and Bio-Acoustics, October 25–26, 1955. June 1, 1956, CHABA Report No. 5. Technical Report No. 8 to the Office of Naval Research from the Central Institute for the Deaf, Contract Nonr 1151(01), NR 140–069.

5. "Monitoring Audiometry and the Medical Disposition of Cases of Hearing Loss," final report of working group 25. June 1957, CHABA Report No. 6 Technical Report No. 11 to the Office of Naval Research from the Central Institute for the Deaf, Contract Nonr 1151(01), NR 140–069.

CHABA memorandum reports

1. "Evaluation of Methods for Reducing Noise from Jet Aircraft Engines in Flight," final report of working group 24. May 1956 CHABA Memorandum Report No. 1. Technical Report No. 6 to the Office of Naval Research from the Central Institute for the Deaf, Contract Nonr 1151(01), NR 140–069.

2. "Hearing Conservation Data and Procedures," final report of working group 21. June 1956, CHABA Memorandum Report No. 2. Technical Report No. 7 to the Office of Naval Research from the

Central Institute for the Deaf, Contract Nonr 1151(01), NR 140–069.

3. "Estimate of Performance of Jet Engine Noise Suppressors for Flight Use," final report of working group 30. June 1957 CHABA Memorandum Report No. 3. Technical Report No. 13 to the Office of Naval Research from the Central Institute for the Deaf, Contract Nonr 1151(01), NR 140–069.

4. "Instrumentation for the Measurement and Generation of High Intensity Sound," final report of working group 29. September 1957 CHABA Memorandum Report No. 4. Technical Report No. 14 to the Office of Naval Research from the Central Institute for the Deaf, Contract Nonr 1151(01), NR 140–069.

CHABA annual reports

1. First annual report of the Armed Forces—National Research Council Committee on Hearing and Bio-Acoustics. June 1, 1954, CHABA Report No. 2. Technical Report No. 2 to the Office of Naval Research from the Central Institute for the Deaf, Contract Nonr 1151(01), NR—140—069.

2. Second annual report of the Armed Forces—National Research Council Committee on Hearing and Bio-Acoustics. June 1, 1955. Technical Report No. 3 to the Office of Naval Research from the Central Institute for the Deaf, Contract Nonr 1151 (01), NR—140–069.

3. Third annual report of the Armed Forces—National Research Council Committee on Hearing and Bio-Acoustics. June 1, 1956. Technical Report No. 9 to the Office of Naval Research from the Central Institute for the Deaf, Contract Nonr 1151(01), NR—140–069.

4. Fourth annual report of the Armed Forces—National Research Council Committee on Hearing and Bio-Acoustics. June 1, 1957. Technical Report No. 10 to the Office of Naval Research from the Central Institute for the Deaf, Contract Nonr 1151(01), NR–140–069.

5. Fifth annual report of the Armed Forces—National Research Council Committee on Hearing and Bio-Acoustics. June 1, 1958. Technical Report No. 15 to the Office of Naval Research from the Central Institute for the Deaf, Contract Nonr 1151(01), NR—140–069.

Reports now in preparation

1. Final report of working group 22 (title not yet selected) CHABA Report No. 7. Technical Report No. 12 to the Office of Naval Research from the Central Institute for the Deaf, Contract Nonr 1151 NR—140–069.

2. Final report of working group 32 (title not yet selected) CHABA Report No. 8. Technical Report No. 17 to the Office of Naval Research from the Central Institute for the Deaf, Contract Nonr 1151(01), NR—140–069.

3. Sixth annual report of the Armed Forces—National Research Council Committee on Hearing and Bio-Acoustics. June 1, 1959. Technical Report No. 16 to the Office of Naval Research from the Central Institute for the Deaf, Contract Nonr 1151(01), NR—140–069.

CHABA reports and miscellaneous reports presented at CHABA meetings that have also been published elsewhere

1. Glorig, A. and Quiggle, R., "A Hearing Conservation Data," Noise Control, 2: 34–42, November 1956.

2. "Recent Progress in Hearing and Bioacoustics," fourth CHABA meeting. The speeches of Maj. Gen. Silas B. Hayes, MC, USA, Brig. Gen. Marvin C. Demler, USAF, and Rear Adm. Rawson Bennett II, USN. Noise Control, 3: 39–44, May 1957.

3. "The CHABA Statement of Purposes and Methods of Operation," Noise Control, 3: 53–54, November 1957.

4. Davis, H. and Usher, J. R., eds., "What Is Zero Hearing Loss?" Journal of Speech and Hearing Disorders, 22: 662–690, 1957.

5. Usher, J. R., ed., "Problems in Military Audiometry," Journal of Speech and Hearing Disorders, 22: 731–756, 1957.

6. Davis, Hoople G. and Parrack, H. O., "The Medical Principles of Monitoring Audiometry," AMA Archives of Industrial Medicine, 17: 1–20, 1958.

7. Davis, H., "Effects of High-Intensity Noise on Naval Personnel," U.S. Armed Forces Medical Journal, 9; 1027–1048, 1958.

8. Kamperman, G. W., "Measurement of High Intensity Noise," Noise Control, 4: 22–27, September 1958.

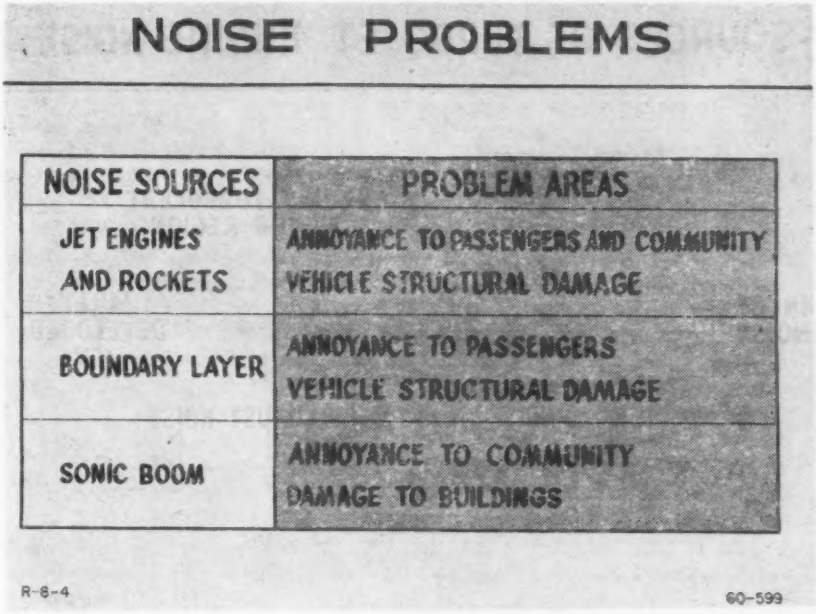
9. von Gierke, H. E., "Vibration and Noise Problems Expected in Manned Space Craft," Noise Control, 5: 144–152.

10. von Gierke, H. E., parts of Chapter 33, "Aircraft Noise Sources" and chapter 34, "Aircraft Noise Control," in C. M. Harris, ed., Handbook of Noise Control, New York; McGraw-Hill Book Co., 1957.

V. Noise Sources and Problems

During the course of the hearings on "Noise: Its Effect on Man and Machine," the principal noise sources in aeronautics and astronautics and the problems associated with them were identified (fig. 5).

FIGURE 5

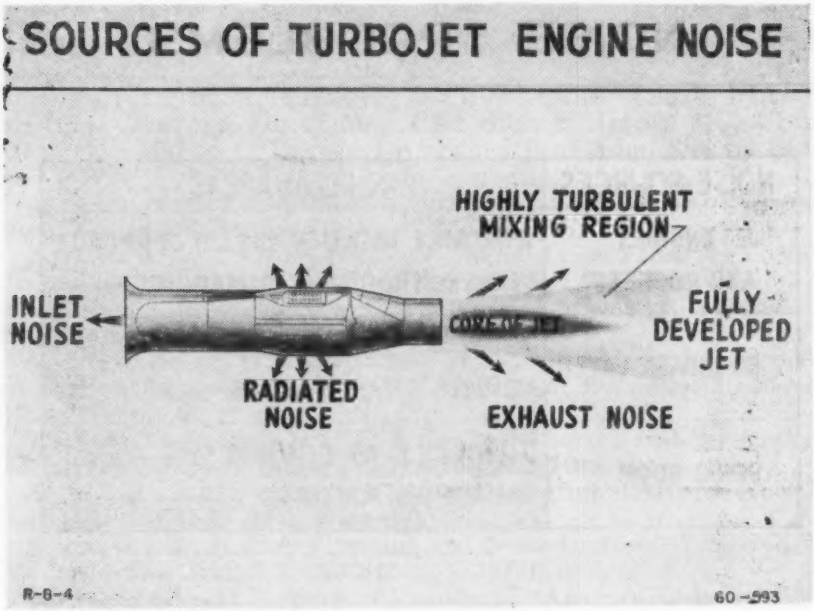


ENGINE NOISE

The turbojet engine

The major noise sources from jet engines originate in three areas. The inlet and compressor region at the front of the engine, the "hot section" or combustion chamber and the exhaust nozzle (fig. 6). Of the three sources, the exhaust noise is the most powerful with respect to sound power level. Inlet noise, on approaches and landings, which can best be described as a compressor whine, has become a major factor recently because of the increase in the number of jet airliners in service. This high frequency noise is almost of equal magnitude at idle engine settings as it is at takeoff power because the compressor is a relatively constant speed device. However, at takeoff power, it is masked by the low frequency roar of the jet exhaust. The noise radiating from the combustion chamber area is of little concern relative to the two major sources at the front and rear of the engine.

FIGURE 6



Jet engine exhaust noise is characterized by a low frequency caused by the mixing of very turbulent, high velocity, high temperature, gases with the relatively cool and stable ambient air surrounding the engine. For this reason, the jet exhaust noise is actually created outside the engine itself, about 5 to 10 tailpipe diameters downstream from the exhaust nozzle or tailpipe. Early attempts to treat this noise source acoustically resulted in the noise suppressors currently attached to the rear of all jet engines in use on commercial airliners today.

FIGURE 7

Figure 7 illustrates three types which have been designed. These suppressors have been only moderately successful in reducing the exit noise of turbojet engines by about 3 to 6 decibels and can only be considered an interim fix. These suppressors also reduce the thrust of the engine by as much as 2 to 4 percent, which is an economic factor of concern to the commercial air carrier. Mr. S. G. Tipton, president of the Air Transport Association, in a memorandum enclosure to a letter for the record states:

> The use of noise suppressors results in an average 4-percent increase in flying time and fuel consumption on short-range flights. They account for an average 2-percent increase of flying time, and a 9-percent increase in fuel consumption on long-range flights.
>
> As of August 1, 1960, there were 13 U.S. air carriers operating a total of 169 turbojet-powered transports. A cost accounting breakdown of the additional monthly operating costs due to the use of suppressors made by one carrier now operating a fleet of 24 jet aircraft, is as follows:

	Per month
Increased operating cost (level flight)	$181,690.83
Increased operating cost (climb)	29,458.98
Payload loss due to suppressor weight	23,592.16
Payload loss due to fuel weight	4,191.52
Repairs	2,000.00
Total	240,933.49

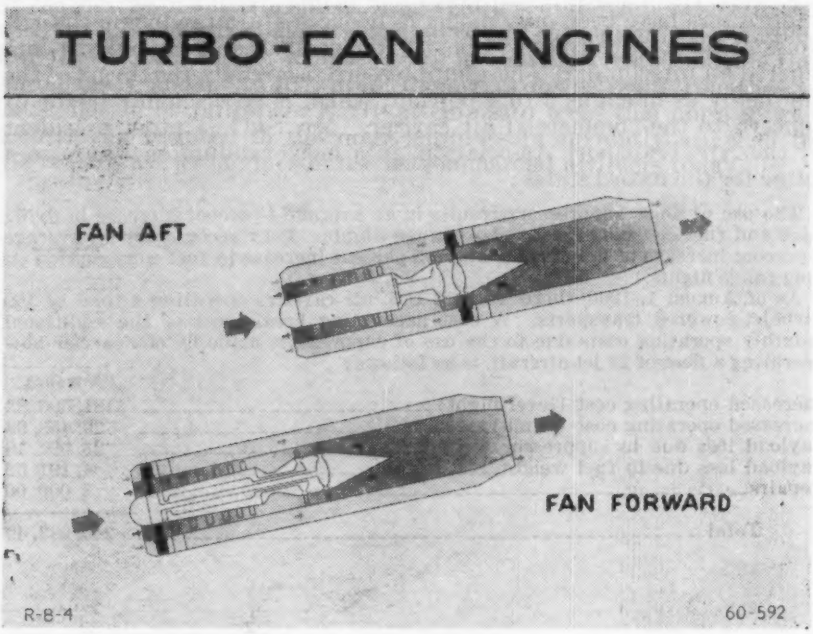
Applying this figure to the total turbojet fleet now in operation, we can conclude the carriers now operating turbojet aircraft are paying approximately $1,700,000 per month for noise suppressors.

The limited success with jet exhaust noise suppressors was achieved with considerable cost in research and development by engine and airframe manufacturers. One concern invested over $15 million in noise suppressor research and development, and it is estimated that between $30 million and $50 million has been spent in this area to achieve a limited improvement in noise reduction.

The turbofan engine

The indifferent success of this noise suppression exit nozzle forced the aviation industry into a search for a better method of achieving noise reduction without paying the penalty of reduced performance and increased operating costs. Research was initiated for the design of a turbojet engine through which a larger volume of air could be moved and yet achieve a decrease in jet exhaust exit velocity. Current engines now in use have a jet exit velocity of about 2,000 feet per second, and hence a rather high noise level. As a result of this research effort, the turbofan, or bypass engine, has been developed which moves large volumes of air at reduced jet exit velocities of 1,400 to 1,500 feet per second. This reduction in exit velocity is significant since the sound energy emanating from the engine varies approximately as the eighth power of its exhaust velocity. Figure 8 illustrates two approaches to the design of such an engine.

FIGURE 8



Although the turbofan engine development did achieve lower jet exit velocities and hence less noise at the rear of the engine, a new noise was added—the fan whine. The fan whine is a discrete high-frequency noise quite similar in character to the compressor whine. Engine manufacturers therefore resorted to acoustically treating the duct or shroud surrounding the fan portion of the engine to have it act as a resonator. As stated earlier in the report, this type of attenuator absorbs the high-frequency fan and compressor noise without appreciably affecting the overall sound pressure level. Current "fan" engine designs are said to achieve a 9–10 PNdb reduction in noise and it is hoped that additional engineering effort in this direction can result in reducing the source noise another 5 PNdb. NASA has inaugurated a turbofan research program quite recently, which it is hoped will provide significant basic noise research data to engine manufacturers.

Large rocket and missile noise

Heretofore, the noise created by large rockets and missiles has not been of much concern to the average citizen. Most of this work has been experimental in nature, conducted at a few relatively remote testing and launching sites. New noise problems lurk on the horizon as these rocket engines become larger, as they must, to achieve the thrust necessary to meet the needs of national defense or to place ever larger payloads into space to support man's insatiable curiosity concerning his universe.

Large rocket engines, such as Atlas and Titan generate in the neighborhood of 350,000 pounds of thrust. Saturn, a space booster, currently under development by NASA, develops 1,500,000 pounds of thrust. These rockets are many times more powerful than today's turbojet engines which develop between 15,000 and 25,000 pounds of thrust. The postulates associated with meeting this problem were clearly outlined by Dr. L. L. Beranek in his prepared statement to the committee:

> The high-power rocket engines of contemporary and future space vehicle designs pose some new noise problems. Along with the higher jetstream power of these engines there is a corresponding increase in the sound radiated. Some of the engines contemplated for the near future will have as much as 20 db greater sound radiation than the most powerful turbojet engines in operation today. Furthermore, the rocket engines tend to radiate large amounts of noise in the subaudible range (below about 20 cycles per second). Noise in this range of frequencies will give rise to new reactions by human beings and to greater potential damage to building structures.
>
> Almost no attention has been paid to the possibility of achieving noise reduction of rocket engines. Although some information is already available for achieving a limited amount of noise reduction by natural techniques (i.e., techniques whose primary function is something other than noise control, such as jetstream deflectors and water spray addition) almost no test sites are being designed today with this information in mind.
>
> Information on the amount of noise reduction afforded by these natural devices is needed, and, when determined, it should be communicated to site designers so that they can make maximum use of what is in essence "free" noise reduction. Furthermore, almost no attention has been paid to the possible application of diffusing techniques such as those now used for noise control on turbojet engines. While the amount of noise reduction to be expected from such devices is not large, we should not overlook this important possibility. Finally, no attention seems to have been given to the possible design of acoustically closed test cells for static testing of rocket engines. Today such tests are always carried out in the open or at best in a hardened excavation. We know that the development of the turbojet engine was greatly facilitated by the availability of noise-reduc-

ing engine test cells. No comparable development appears to be underway for the testing of rocket engines.

There appear to be three problems associated with rocket noise that deserve immediate attention and concentrated research effort: (1) the establishment of rational criteria for noise from rocket engines, (2) the study of outdoor propagation of rocket noise, particularly over very long distances, (3) the development of noise control methods, which we have already discussed above.

The task of selecting a rational criterion for noise in communities surrounding a rocket engine test or launching site is not an easy one. Although many such military sites are now operative, there are little direct data bearing on the problem of community response to the noise. We need community noise and reaction surveys such as were carried out starting about 10 years ago when jet aircraft operations began to be important. Without such surveys, it does not appear possible to proceed with a rational evaluation of the overall problem. In addition to the reaction of humans in such surveys we must also study possible building damage, particularly at locations very near (less than 1 mile) the test area.

Because of the large amount of low-frequency energy radiated by rocket engines, we need to study the problem of propagation of long-range low-frequency sound through the atmosphere. In the past 10 years significant strides have been made in understanding the propagation of high-frequency sound (e.g., sound from present-day aircraft) through the atmosphere above the ground, mainly because of the interest in turbojet aircraft noise. The studies have heretofore been confined to noises propagated over distances of only a few miles. In the case of rocket engine noise we need information on long-range propagation (up to at least 10 miles) for low-frequency noises in the range of about 1 to 100 cycles per second. Because of the longer distances and the lower frequencies, high-altitude atmospheric effects play an important role in the propagation. It is often observed that noise from test sites can be focused by the atmosphere and at great distances noise levels will occur that are comparable to the levels adjacent to the test site. We need to develop improved upper-air meteorological techniques for use in conjunction with rocket tests to predict and thus avoid the occurrence of such focusing phenomena.

BOUNDARY LAYER NOISE

Definition

Aerodynamic boundary layer noise is a phenomenon associated with the high-speed passage of a body through the atmosphere. It can be described as the extremely thin, "sticky," layer of air next to the outer skin of the vehicle. This boundary layer behaves like a viscous friction-creating fluid at high speeds and temperatures: the higher the speed—the more serious the effects. Boundary layer noise creates several problems for jet aircraft, rockets, missiles, and manned space craft. These are sonic fatigue of the basic vehicle structure; interference with speech communications; noise-induced failure of instruments, instrumentation, guidance systems, and auxiliary power supplies; and for the astronaut, possible psychosomatic problems during reentry.

Sonic fatigue

Acoustic excitation has been a recognized problem for designers of jet aircraft missiles and rockets for many years. Research work to minimize it has increasingly occupied NASA and the aircraft industry as the speeds of the vehicles continue to rise. Sonic fatigue damage is a function of the surface pressures present in the boundary layer (directly related to the velocity of the vehicle) and the cumulative time or frequency of structural exposure to these damaging surface pressures. Noise-induced structural damage occurs at approximately 140 decibels. Figure 9 is a pictorial time history of the deterioration of a metal panel subjected to a discrete frequency noise field at a sound power level of 158 decibels.

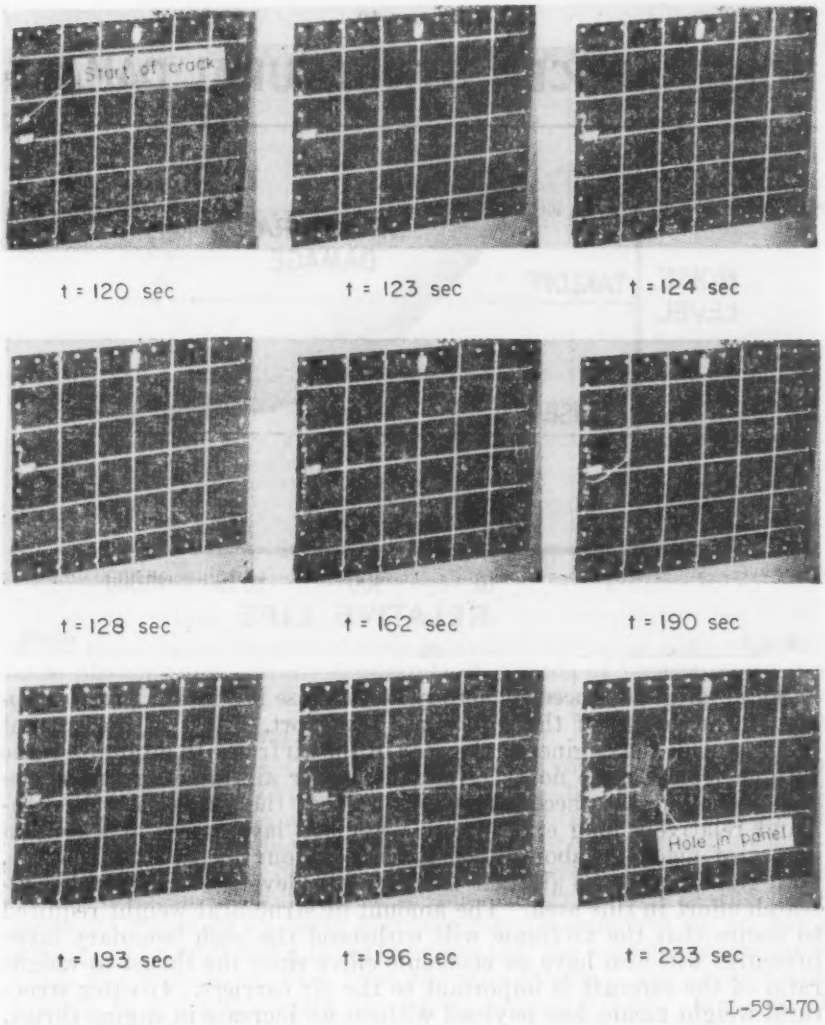
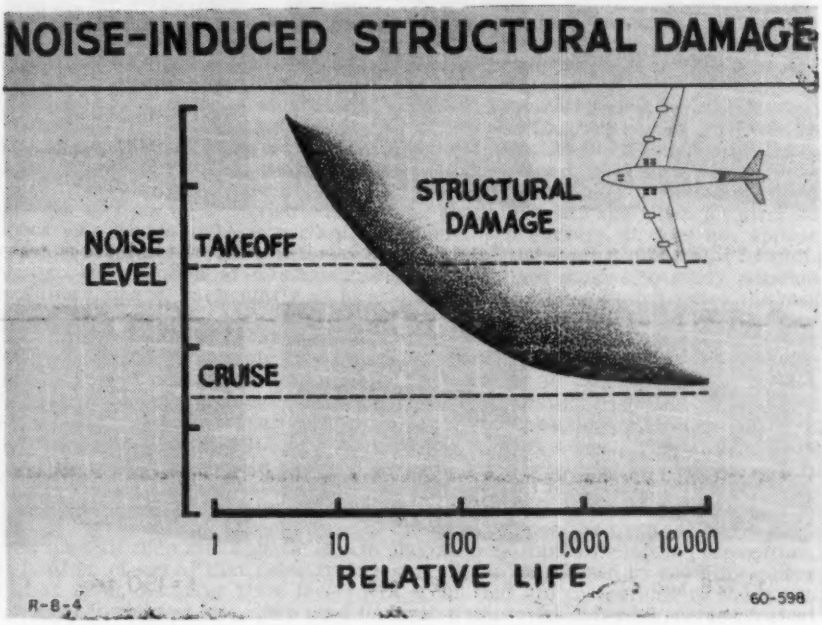


FIGURE 9.—Crack growth of 0.032-inch flat panel at a discrete noise level of 158 decibels.

Sonic fatigue has been a problem for today's subsonic transport aircraft, but not a major one, since exposure time is relatively limited to the takeoff phase of the flight profile. This is due to the mounting of the engines on the wing structure where the high velocity jet exhaust gases create heavy boundary layer noise excitation toward the tail of the aircraft at takeoff power. Figure 10 graphically illustrates the ratio of noise exposure to structural life of a typical subsonic aircraft.

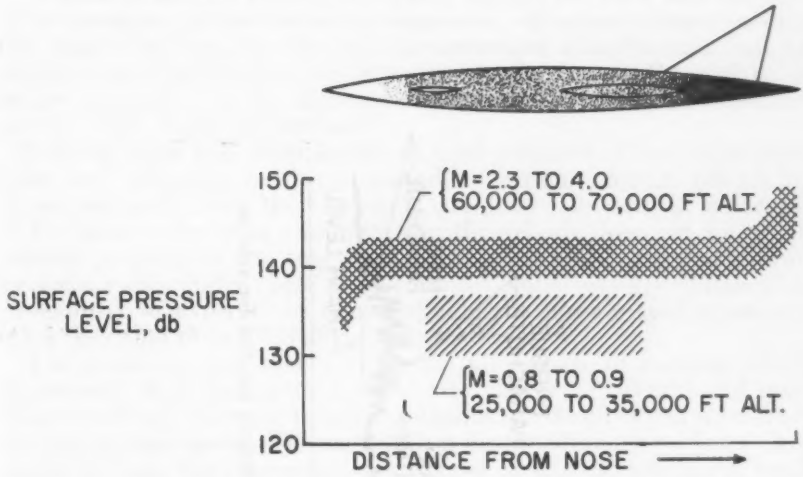
FIGURE 10



Sonic fatigue induced by aerodynamic noise is a more critical problem in the design of the supersonic transport. Most of the current designs place the engines at the rear of the airframe to minimize sonic fatigue from engine noise. New and better airframe structural design techniques are necessary to insure that the structure will withstand relatively long exposure to boundary layer noise at speeds in excess of mach 2 (about 1,500 miles per hour). As stated before, both NASA and the aircraft industry are devoting considerable research effort in this area. The amount of structural weight required to insure that the airframe will withstand the high boundary layer pressures will also have an economic effect since the thrust-to-weight ratio of the aircraft is important to the air carriers. Greater structural weight means less payload without an increase in engine thrust. Greater engine thrust requires larger engines, hence higher fuel consumption. Where the economic trade-off will be is yet to be determined. Figure 11 illustrates the areas affected by boundary layer noise for a supersonic aerodynamic shape. It can be seen that it increases toward the tail, since the sound pressure level increases in that direction to 150 decibels.

FIGURE 11

BOUNDARY LAYER NOISE DURING CRUISE CONDITION



Boundary layer noise has no effect on the community, but it requires that the passengers be well protected from this high intensity noise phenomenon. Many thousands of pounds of insulation are required to achieve that smooth, almost noiseless, ride in jet airliners.

Boundry layer noise and the astronaut

Boundary layer noise surrounding a space vehicle is of concern to the astronaut during two phases of his flight—during launch and exit from the atmosphere and during reentry. Since both of these phases are most critical to the safety of the astronaut, a great deal of engineering effort is being devoted by NASA to determine the magnitude of the problem. Figure 12 is a time history record of the noise measured inside of an early Mercury capsule launched by an Atlas missile. The interesting thing to note is that the boundary layer noise inside the capsule, on exit from the atmosphere is 125 decibels and exceeds, by a slight amount, the rocket noise at lift-off. It is also of longer duration.

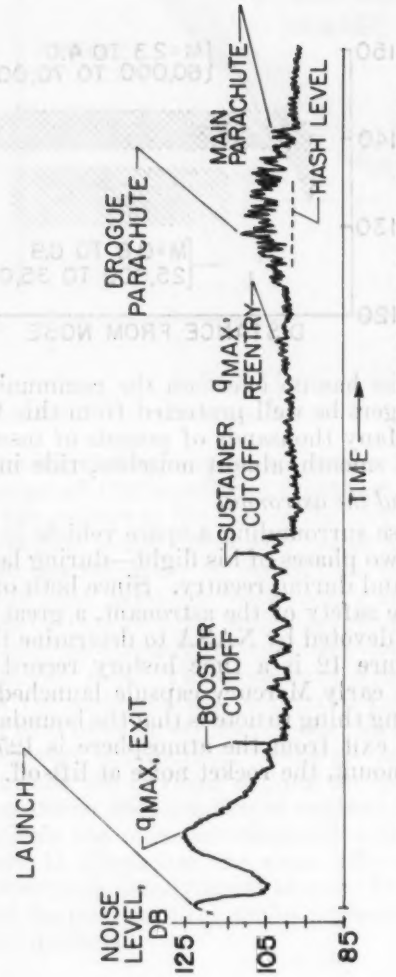


FIGURE 12.—Internal capsule noise level time history for Big Joe vehicle.

During the critical period of the boost phase, it is highly important that communications be maintained with the astronaut should some malfunction develop which requires the initiation of escape action. It is understood that automatic sensing devices are built into the Mercury system to initiate the escape sequence. However, there is always the possibility that, in the end, the astronaut must be told that his vehicle is malfunctioning and he must therefore manually initiate the escape sequence. Under these circumstances, the ability to communicate is of the utmost importance.

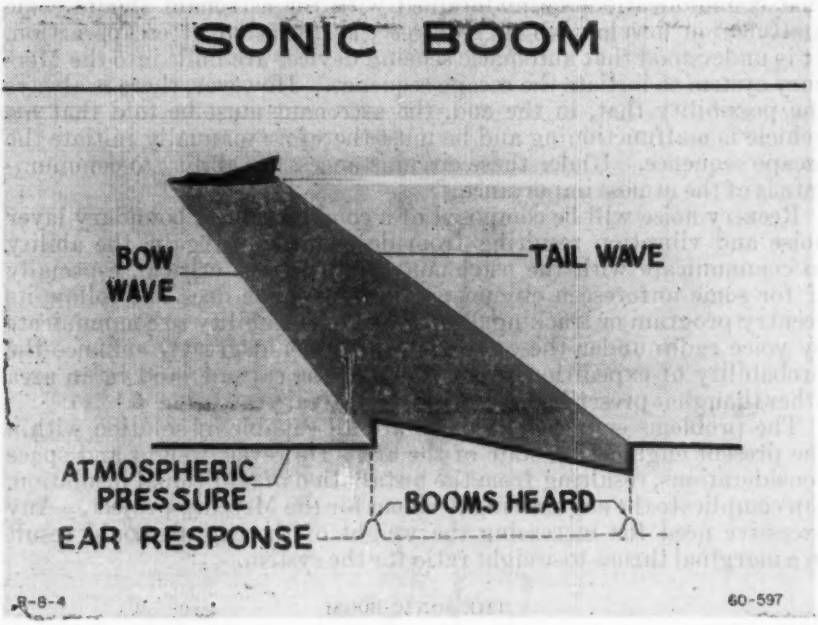
Reentry noise will be composed of a combination of boundary layer noise and vibration resulting from deceleration. Again, the ability to communicate with the astronaut could become critical, especially if for some unforeseen circumstances the vehicle does not follow its reentry program or tracking data is lost. The ability to communicate by voice radio under these circumstances would greatly enhance the probability of expeditious rescue, should the capsule land in an area other than that prescribed as the recovery area.

The problems enumerated above are all capable of solution within the present engineering state of the art. However, weight and space considerations, resulting from the installation of additional insulation, can complicate the engineering problem for the Mercury project. Any excessive need for increasing the weight of the capsule could result in a marginal thrust-to-weight ratio for the system.

THE SONIC BOOM

The sonic boom is the result of a pressure wave generated by an aircraft in supersonic flight. The shock wave forms on the nose and the tail of the aircraft and the intensity of the boom with respect to the ground is a function of flight speed and flight altitude. The boom is normally heard as two distinct noises or shocks just a fraction of a second apart. Under some conditions of flight attitude and atmospheric conditions, the bow and tail wave merge at ground level and only one boom is detectable. Figure 13 pictorially presents the reception of the shock wave by the human ear. The shock wave generated by a supersonic aircraft flying at very high altitudes will be heard as the noise of distant or nearby thunder. At lower flight altitudes, the shock wave can be felt as a sharp jolt, as well as being heard. If the aircraft is low enough and close enough, the overpressure generated at ground level can, under certain circumstances, damage windows and plaster.

FIGURE 13



NASA has conducted a comprehensive wind tunnel and flight test program in an effort to learn more about the physics of the sonic boom. Basic knowledge gained in this manner will contribute to finding means for controlling the magnitude of the boom. NASA is currently engaged in a joint flight test program with the Tactical Air Command and the Federal Aviation Agency in a study of intense sonic booms.

The supersonic transport and shock wave noise [13]

The supersonic air transport, when developed, will produce a shock wave noise source which was not a problem with subsonic airliners. The sonic boom could be created during the climb, cruise, and descent phases of the flight profile if proper precautions are not taken.

Although the resulting sonic-boom disturbances may be observed throughout these phases of the flight, the most serious problems are associated with the acceleration since this may be accomplished at a reduced flight altitude. If proper precautions are not taken, shock-wave noise pressures may be of sufficient intensity to damage parts of ground building structures such as windows, in addition to causing annoyance.

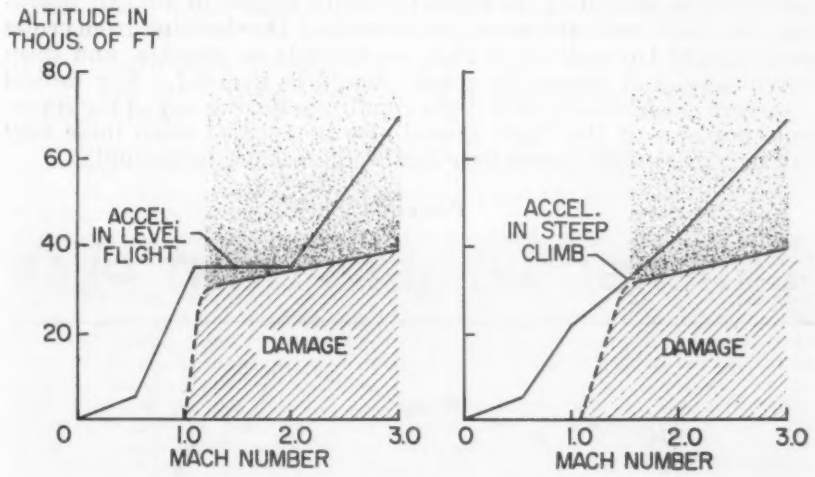
Figure 14 suggests two approaches to solving the acceleration problem: one a level-flight acceleration and the other an acceleration in steep climb. Airplane flight mach number is plotted on the horizontal scale and airplane altitude on the vertical scale. The hatched area represents combinations of mach number and altitude which may

[13] NASA Technical Note D–423, entitled "The Supersonic Transport—A Technical Summary."

result in damage to structures on the ground. The shaded area toward the top represents combinations of mach number and altitude for which sonic booms will be observed on the ground and which may be annoying but will not cause damage. The main objective in the flight operation is to travel from ground level to cruise conditions without intersecting the damage area. NASA flight studies have shown that increasing altitude is a very powerful factor in reducing the sonic-boom intensity. This leads to the proposed procedure illustrated on the left-hand side of figure 14. This consists of a subsonic climb to relatively high intermediate altitude, then a level-flight acceleration to a mach number of about 2, and then a subsequent climb and acceleration to cruise condition. Note that in figure 14, 35,000 feet is the minimum acceptable altitude for a level-flight acceleration to avoid ground damage; a higher altitude than 35,000 feet is highly desirable to minimize adverse community reaction and to lessen further the possibility of ground damage.

FIGURE 14

CLIMB SCHEDULES TO AVOID DAMAGE



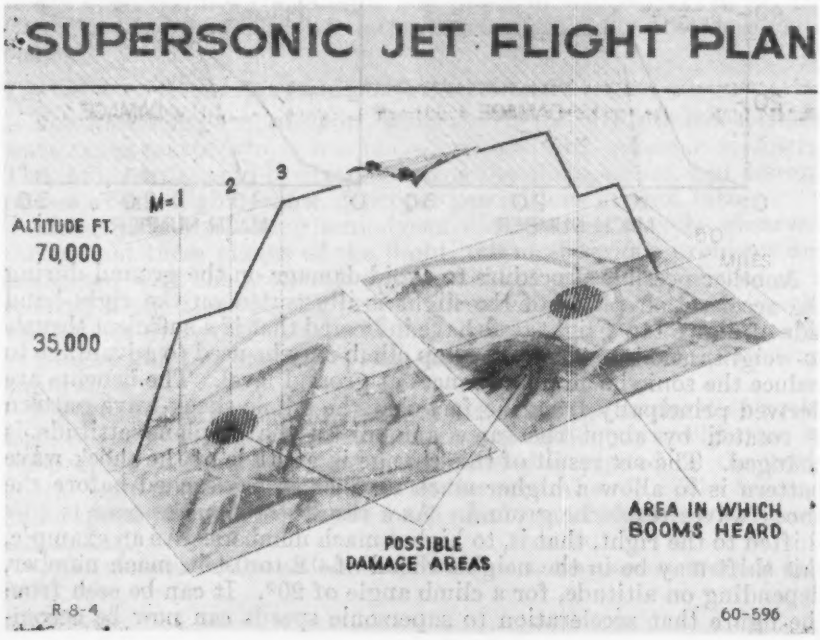
Another possible procedure to avoid damage on the ground during the acceleration phase of the flight is illustrated on the right-hand side of figure 14. Flight tests have indicated that if a sufficient thrust-to-weight ratio is available, a steep climb may be used to advantage to reduce the sonic-boom disturbances at ground level. The benefits are derived principally from the fact that the whole shock-wave pattern is rotated by about the same amount as the airplane attitude is changed. The net result of this change in attitude of the shock-wave pattern is to allow a higher mach number to be reached before the shock waves reach the ground. As a result, the damage area is now shifted to the right, that is, to higher mach numbers. As an example, this shift may be in the neighborhood of 0.2 to 0.4 in mach number, depending on altitude, for a climb angle of 20°. It can be seen from the figure that acceleration to supersonic speeds can now be accom-

plished at a lower altitude without intersecting the damage region providing, of course, that the aircraft remains in a climb attitude.

The results of recent NASA studies have suggested that the low mach number part of the damage-area boundary, as represented by the dashed line in figure 14, is unstable and is sensitive to atmospheric wind and temperature gradients. The high mach number part of the damage-area boundary, as represented by the solid line, was noted to be relatively stable and is not very sensitive to changes in the atmospheric conditions. These results suggest that the most reliable flight procedure to avoid the damage area is the one shown on the left-hand side of figure 14 since the nearest approach to the damage region occurs where its boundary is most stable. On the other hand, the steep-climb procedure involves a close approach to the damage area in the region where its boundary is unstable. The implications here are that atmospheric conditions such as strong tail winds and/or temperature inversions might tend to neutralize any benefits attained as a result of the steep-climb procedure. Atmospheric variations would present no problem in the level-flight acceleration procedure.

For a given size airplane, only small benefits would be gained from changing its shape to reduce the boom intensities. Thus, figure 15 shows that the practical solution to the sonic-boom problem lies in the manner of operation of the aircraft. With regard to aircraft operation, two additional statements can be made. Deceleration from cruise speed should be made at as high an altitude as possible, and steep descent angles at supersonic speeds should be avoided. Any radical departures from steady-level flight conditions during any of the supersonic portions of the flight should also be avoided since these may lead to intense sonic booms over localized areas on the ground.

FIGURE 15



VI. Hearing Highlights

The following excerpts from the hearings held by the House of Representatives Committee on Science and Astronautics provide a brief digest of the opinions of the witnesses and selected persons who were asked to provide written opinions for the record. The latter were published as an appendix to the hearings.

STATUS OF NOISE RESEARCH

Ira Abbott, Director, Office of Advanced Research Programs, National Aeronautics and Space Administration, in answer to a question concerning a research solution to the noise problem replied:

We do have a noise research program, sir, which I have very briefly outlined in my statement.

The second part of your question is more difficult to answer because it uses the term "solution to the problem" and this may mean various things to various people.

The term "solution to the problem" might mean, for instance, that the noise would be reduced to such a low level that it would neither cause any damage nor annoy anybody.

I, myself, cannot foresee such a fortunate outcome. However, I do believe that this research program, together with cooperative efforts by everybody else concerned, can contain the noise problem within tolerable limits. This is going to be a hard thing to do, but I do believe that it can be done. * * *

Dr. Richard Bolt, Associate Director (Research), National Science Foundation, gave a very illuminating opinion as to the status of research as follows:

Just where do we stand in scientific and engineering research relevant to this field? First, regarding paths in the noise system, the scientific literature now contains a well-rounded body of information about the transmission of sound through gases, liquids, and solids.

Many special studies have been done on sound propagation through inhomogeneous media, such as the atmosphere and oceans. (Research in underwater sound contributes backup knowledge pertinent to airborne sound.) Although there are still many unresolved fine points, such as the specification of meteorological data for use in predicting sound propagation through the atmosphere, and further research on many such points should be encouraged, the state of knowledge regarding sound transmission is not a bottleneck in the solving of aviation noise problems.

The situation regarding sound sources is about the same. The major conceptual breakthrough here was a theory, put forth by Mathematician Lighthill of England, that describes the generation of noise by turbulent motion in a fluid.

Lighthill's theory, extended by several other scientists, makes it possible to estimate rather well the amount of noise that is produced by the exhaust stream of a jet engine.

Again, there are many scientific fine points that need clarification. In general, however, our ability to handle noise problems is not limited significantly by lack of knowledge regarding the basic physical principles of sound generation—though much more could be done in applying this knowledge to the design of propulsion systems.

Regarding noise receivers and criteria, two aspects are reasonably well understood. The way in which noise interferes with speech has been thoroughly analyzed and we have quantitative criteria for calculating the percentage of speech intelligibility for person-to-person communication in almost any describable noise environment.

Also, the effect of noise in producing hearing impairment in humans is fairly well established. We have criteria that set safe limits on long-duration exposure of man to steady noise. Criteria for short-duration and impulse-type noise need and are receiving further study.

Preliminary standards relating noise exposure to hearing impairment have been set forth in documents by the American Standards Association, the Armed Forces, and other organizations.

The general problems of "disturbance," on the other hand, are more difficult and are less well understood. The degree to which a person is annoyed by noise depends not only on the characteristics of the noise he is hearing at the time, but also on the past history of his noise exposure, on his knowledge about the source of the noise, and on a wide range of psychological, social, and economic factors. In some respects, disturbance by noise is like disturbance by any other means that produces stress, intrusion of privacy, fear, worry, interruption of sleep, and the like.

Thus, any basic research that bears on these complex responses of people to external stimuli may help us better to understand these responses to noise. A number of the research programs listed in appendix A relate to these psychological and physiological problems, and there is a large body of literature pertaining to this subject.

Nevertheless, the most knowledgeable specialists on bioacoustic problems agree that there is much more to learn and that we do not have an adequate understanding of complex human behavior.

When noise involves a group or community of people, not just one individual, the problems become vastly more complicated. Whether or not a given community organizes to complain against noise, such noise from air operations, depends not only on individual reactions but also on the emergence of group leadership, on the extent to which the leaders are familiar with ways in which to register complaints and to organize further action, and on other social factors. These basic problems in social and psychological science are inadequately defined and still await thorough scientific investigation.

Meanwhile, useful progress has been made by opinion surveys and empirical studies of community response to noise. The results from these activities, supplemented by recent research on perceived noise levels, form the basis of the criteria now available for estimating the nature and magnitude of community reactions to noise exposure.

The National Opinion Research Center, under NACA sponsorship, conducted opinion polls in eight cities containing major airports. Reactions of thousands of residents, living at different distances from the airport, were sampled and at the same time physical measurements were made on the noise conditions in the community.

Subsequently, under Air Force sponsorship, the NORC conducted studies in communities neighboring on military airbases. These studies were aimed at establishing basic principles and relevant variables in the complex reactions of communities.

The engineering criteria now in use for predicting expected responses of people in communities are derived from empirical evidence from scores of case histories. The evidence shows that the vigor of response (complaint or other action) depends on a large number of variables, including intensity and frequency spectrum of the noise, number, and duration of exposures, time of day or night, season, economic level of community, type of activity (sleep, reading, listening to TV, and so forth) that is interfered with, and past experience of the community with the noise.

Taking such variables into account, the engineer can use the criteria to predict with reasonable accuracy the likely reactions to any proposed aviation facility or operation. Such engineering analyses have proven useful and reliable in guiding the planning of many airbases and airports.

Responses of equipment to noise and vibration have been studied but still raise some unanswered scientific questions. There is today a great deal of activity in engineering research on damage, fatigue, and malfunctioning of structures, electronic components, and control systems exposed to intense noise and vibration.

These efforts could be more effectively carried out if we knew more about the underlying acoustical and mechanical interactions and the solid state physics at the atomic and molecular level.

Thus, some of the work in materials research, which is now receiving increased national attention, may be expected to improve our understanding of the effects of intense noise on aircraft and missiles.

Dr. Horace O. Parrack, Coordinator of Noise and Vibration Control, Wright Air Development Division, Wright-Patterson Air Force Base, Dayton, Ohio, summed up his opinion as follows:

In the area pertaining to acoustic energy sources, and here you will recall we used primarily physical science techniques, we have the following results:

First, the basic mechanisms by which jet-type propulsion systems generate noise have been determined and described. However, additional research on these mechanisms may be requiredin connection with the most advanced rocket engines.

Second, it has been shown that jet and rocket engine sources cannot be designed or modified to achieve major reductions of the acoustic energy, and that is true at least up to the present date. Future engines of another category, such as have been mentioned here this morning, that are not now in use, may raise a ray of hope, but I have long since learned that it is highly undesirable to be overly optimistic about what these new things will do until we have actually developed them and tried them out in operational situations.

Third, it has been demonstrated in cooperation with NACA and industry that airborne suppressors cannot produce major reductions in jet engine noise without introducing reductions in aircraft performance that are not acceptable to the Air Force.

Fourth, the acoustic energy output, under all of the important operating conditions of the sources, of current U.S. Air Force propulsion systems have been determined and described quantitatively.

Fifth, methods have been developed for estimating the acoustic energy output of propulsion systems using data that define their design parameters, and these estimates can be made before the prototype systems have been built. Except for the most advanced rocket motors, these methods have been experimentally verified to a large extent.

Sixth, principles have been discovered and applied in developing methods for estimating acoustic energy levels on the ground that result from the flight of aircraft overhead.

Seventh, aerodynamic generation of noise, at the surface of aircraft has been studied and the mechanisms of generation determined except for flight at high mach numbers.

Eighth, theories of the generation of shockwaves at supersonic speeds have been developed, and these theories have been experimentally substantiated in a general way except for flight at very high mach numbers.

Gen. Elwood R. Quesada, Administrator, Federal Aviation Agency, summed up the research efforts of that Agency as follows:

As the first phase of the research program on aircraft noise, research and development is being conducted through studies of the aircraft noise problem, and by evaluation of efforts going on in industry.

Attention is being given to what is being done and planned to alleviate the noise problem, such as the state of the art in engine and suppressor design.

We are also evaluating the efforts being made to alleviate the noise problem at the public relations level, and the efforts of noise measurement.

The goal of this initial effort is to pull together all of the research and experience on the noise problem. The basis is being laid for recommendations as to immediate action where such action would contribute to the alleviation of the noise problem, with the idea of guiding further research and development work into the most productive channels, and avoiding duplicate efforts with other Government agencies and industry.

A preliminary memorandum report on "Sound Barriers and Turbojet Engine Runup" has already been received from Cornell Aeronautical Laboratory. This proposal is to investigate the sound-attenuating properties of batteries of water sprays, which work both by acting as a solid carrier would, and by cooling the hot, turbulent gases. The final report on the whole initial program is due later in August.

A concerted effort is being made to investigate the ancillary problem of ground aircraft noise. The costs and effectiveness of both fixed and portable barriers against noise generated by aircraft on the ground are being computed.

It would appear that barriers are not a cheap cure-all for ground noise, but they would definitely be a reasonable solution in certain particular situations.

An example of sound barrier research is the proposal of the spray barrier made by Cornell Aeronautical Laboratories which was mentioned above.

The spray barrier has the particular advantage that it would be "erected" only when a plane was about to take off and thus would not be in the way of a landing aircraft. Such a barrier might be a reasonable solution to the noise problem at San Francisco International Airport, where the neighborhood town of Millbrae exists only a few hundred feet from the end of a runway, and is subjected to intolerable noise, direct exhaust, and soot, when jet aircraft use that runway for takeoff.

There are other circumstances where barriers might be feasible. For example, a new runway at Los Angeles International Airport runs parallel to and only about 1,000 feet from a high-cost residential area.

According to our calculations, a wall or earthen dike 20 feet high would afford very substantial relief to the adjoining residential area. Experimental sound barriers will be evaluated at NAFEC if such evaluation is necessary.

The Federal Aviation Agency has tentatively selected for adoption as the U.S. standard the British RAE visual glidepath indicator which provides information to pilots on the correct angle of descent.

While this device is primarily directed toward safety, it does make some contribution to noise abatement by providing guides to pilots, which enables them to remain at or above the glidepath angle on approach.

This indicator will enable the pilot to maintain better control of his glidepath on landing and thus assure that his landing path is over a controlled course at prescribed heights, confining the noise to a defined area.

In conclusion, while noise abatement is a serious national problem today, and will continue to be a serious problem in the future unless some spectacular breakthrough in noise suppression at the source is achieved, we feel that we are making reasonable progress within the limitations of existing technology and through the courses of action which I have outlined.

Increased jet operations in critical areas and the establishment of this service at more airports will amplify the problem to some degree. In all candor, the future outlook has both bleak and promising aspects.

There are no immediate and dramatic means of completely stifling the sounds that accompany essential air transportation. Despite this, increasingly effective methods of reducing and tolerating noise are being developed and put into effect.

With advanced planning and the concerted effort and cooperation of the industry, the airport operators and the affected communities, we believe that the noise nuisance can be held to an acceptable level commensurate with progress in air transportation.

Dr. Hallowell Davis, director, Central Institute for the Deaf, St. Louis, Mo., former executive secretary of the Armed Forces—National Research Council Committee on Hearing and Bio-Acoustics (CHABA), in a letter for the record provided these opinions on the general noise problem:

The chart of CHABA working groups looks ominous with only four new ones in the last 2 years. I believe, however, that there will always be a need for CHABA and business for CHABA because none of its major problems will ever really be solved. If they do appear to be solved it will be only indirectly because of changes in the technology of warfare, political decisions or social developments. I say this because the major CHABA problems are problems of human tolerance for noise and noise is here to stay.

The CHABA problems differ from one another chiefly in the nature of the stress that noise imposes. It may be direct bodily injury, it may be impairment of hearing, it may be interference with psychomotor performance or with speech communication, or it may be simply annoyance.

The problem is to balance the cost of prevention or cure against the risks, difficulties, or annoyance. This is a difficult balance to estimate as it is hard to find a common denominator. The most obvious common denominator is the economic cost in dollars, as when veteran's compensation for hearing loss is compared to the cost of noise control and hearing conservation, but elsewhere we must deal also with very different considerations such as the success of military operations or possible undesired legislative control.

In any case the balance is dynamic and it may be upset by new factors. Such a new factor may be a technological advance such as jet propulsion. This is actually what created the military noise crisis of 1952 that led to the establishment of CHABA. Or it may be political and judicial decisions such as the enactment and the interpretation of workmen's compensation laws. These laws and decisions created the industrial noise crisis just a few years earlier. Or it may be a sociological change or pressure, such as the universal growth of cities and the tendency of their suburbs to surround airports. The point is that any upset in the balance means either a CHABA crisis or a CHABA problem solved. Usually the stress or the expense is increased, and there is a new noise crisis.

The major CHABA problems each involve a balance between noisemaking and some undesired effect of the noise of man. Technological advance or sociological developments are upsetting the old balances. There is actually a common general pattern which CHABA has found empirically in dealing with one problem after another. In general terms and as a pattern for the future, here are the steps:

(1) Clear away the fog of mystery and fear and emotion that surrounds any novel physical stress, whether it be radio waves, ultraviolet light, electron beams, alpha particles, ultrasonics, or high intensity noise. The surest way is through objective tests and clear exposition at the popular level. Quantitative measurement helps greatly, but even in advance of precise measurement direct qualitative demonstrations may hold the line.

(2) Find ways to measure both the stress and the effect. The concepts of noise exposure (with its emphasis on time factors as well as on intensity and spectrum), of speech interference level and of hearing impairment illustrate such ways of measuring. This step is in the CHABA area, and it is a big step.

(3) Find the relation between stress and effect. The relations of hearing loss to noise exposure is a familiar example. The relations will never be precise because of the many variables that are involved, including biological variability. Others are literally as fickle as the weather. At least, however, statistical relations can be established. This step also is in the CHABA area, and is probably the most difficult step of all.

(4) Establish criteria for the stress even if they must be crude interim criteria. This is not entirely a technical CHABA affair because certain broader decisions must be made as to the degree of risk, of extra cost or effort, or of annoyance that is acceptable. It is interesting that international standard curves are being proposed for use in establishing criteria for noise exposure, for speech interference and for annoyance. CHABA can participate in formulating criteria.

(5) Establish systems of monitoring in order to detect and deal with either—

(*a*) an unexpected increase in the amount of stress imposed on individuals, or

(*b*) an unacceptable amount of injury, annoyance, etc., such as should require a modification of criteria, or

(*c*) the cases of individual injury, such as hearing loss, that must be expected on a statistical basis with any reasonable criterion levels. With careful monitoring they are detected early before impairment is severe. Many techniques of monitoring are in the CHABA area, although the choice of the "monitoring levels" that indicate the necessity for action involves broader decisions. The measurements used in monitoring may be strictly acoustic, such as those for noise exposure, speech interference level, and perhaps annoyance levels. They may be psychoacoustic, as for hearing level or threshold shift, or they may be strictly medical, psychiatric, or sociological. The latter are outside the CHABA area.

(6) Evaluate the technical feasibility and economic costs of noise control and/or of personal protection. It may be of considerable importance to know in advance the theoretical limits of noise suppression of jets, of ear protection, of sound isolation, etc.

(7) Improve and validate criteria continually on the basis of planned experiments and of the experience gained by careful monitoring. Here is the great continuing CHABA task.

(8) Establish acoustic requirements for acceptability of machines and vehicles of all sorts. This again is only partly a CHABA problem, but it is well known that economic costs can be reduced greatly if acoustic requirements exist and are considered early in design and planning. This principle extends to the planning of airports, truck routes, etc.

(9) Keep the balance between noise and its effects on man in equilibrium by careful monitoring and hope that the problems will be alleviated by new technical advances. This may often happen even before criteria that are scientifically based and validated can be evolved.

All of these steps constitute what we mean by "learning to live with a problem." Modern civilization has many such problems, and noise is one of them. We can perhaps take some comfort in the thought that familiarity breeds acceptance as well as contempt. A favorable emotional attitude toward a stress and particularly toward an annoyance makes as much difference as many decibels of noise control. Social attitudes and social values develop and can often be molded, particularly by making people aware of just what the opposing interests are and where the costs fall. But the basis for persuasion must be knowledge and the basis for knowledge is measurement. CHABA is concerned with knowledge and with measurement.

GOVERNMENT-INDUSTRY COOPERATION: A SAMPLING OF OPINION

Ira Abbott, speaking for NASA:

I have tried to outline the major noise problems in aeronautics and in our space program and have reviewed our current research activities on engine noise, boundary layer noise, the sonic boom, and structural fatigue induced by noise.

I should like to emphasize that these research programs are aimed at providing basic information on the magnitude and characteristics of these noise sources, on the basic principles for decreasing the level of engine and aerodynamic noise, and on techniques for alleviating their effects on structures and their annoyance to communities.

The NASA considers the noise problem to be a serious one. As in other technical areas, we work as part of a team which includes over Government agencies, the manufacturing and aircraft operating industry, the scientific community, and other organizations concerned with the problem.

With regard to aeronautics, our role is to conduct research to assist these other agencies and industry in developing hardware and operating procedures to minimize the noise problem.

Dr. Richard Trumbull, principal Navy witness, in his prepared statement made mention of early recognition for the need of Government-industry cooperation:

Recognizing that this situation was to become worse, the National Research Council Committee on Hearing recommended that "the Navy * * * appoint a small group to gather information on the present knowledge of, and present work in progress on, the subject of acoustic trauma, and in the light of this information to suggest the next steps to be taken in relation to the urgent practical problems arising from high-intensity noise. It is assumed that this group will establish liaison with the Air Force and appropriate industries, and consider the possibilities of combined or cooperative effort in relation to these problems." (29) This noise survey team, supported by an Office of Naval Research contract with the Psycho-Acoustic Laboratory of Harvard University, visited naval and Air Force installations, academic institutions, and aircraft industrial concerns preliminary to observing operations aboard a carrier.

Despite launching frequencies as high as 20 in one 25-minute period, in levels of 124–132 decibels at 35 feet, the earlier study had reported that "only one man was observed to cover his ears with his hands during runup and takeoff, and no ear protection was observed in use during any of the operations." (14) The noise survey team concluded that measuring equipment would need some improvement for exact calibration of afterburner intensities which were registering above 140 decibels. It also was evident that such levels as could be anticipated in the near future would result in nonauditory effects as well. The magnitude of the problem now became apparent as did the immediate need for some interdisciplinary committee to cope with it. At the recommendation of

the Committee on Medical Sciences of the Research and Development Board of the Department of Defense and the endorsement of the National Research Council Committee on Hearing, a group of civilian and military experts organized the Armed Forces—National Research Council Committee on Hearing and Bio-Acoustics (CHABA) at a meeting on December 15, 1952.

This committee with Dr. Hallowell Davis as executive secretary followed the format of one previously established on vision and both were to function under the contract program of the Office of Naval Research, Physiological Psychology Branch. Membership was to be composed of a balanced military and civilian representation with liaison members appointed by other interested Government agencies. Areas of interest were (1) the effects and control of noise, (2) auditory discrimination, (3) speech communication, (4) fundamentals of hearing, and (5) auditory standards.

Dr. Horace O. Parrack, principal Air Force witness, stated:

This program of the Air Force has been fully coordinated within the Air Force by a special technical coordination office. Coordination with other military services has been achieved by utilizing the services of the Armed Forces, National Research Council's Committee on Hearing and Bio-Acoustics, known as CHABA. Coordination with NACA, with other nonmilitary governmental agencies and industry has been achieved in the past by the Technical Coordination Office and by use of the NACA Special Subcommittee on Aircraft Noise, which was inactivated about the time NASA was formed and activated.

D. G. Gilmore, of Vought Aeronautics, stated in a letter to the committee:

Although we admit we have not been in a position to evaluate the overall noise picture, we have not been able to observe any impressive indication of a coordinated program both in Government and in private industry that is oriented to solve the noise problem.

Dan Kimball, president, Aerojet-General Corp., stated:

While we have not been greatly involved in many of the areas, we do feel that there is a coordinated program to solve the noise problem both in Government and in private industry.

Courtlandt Gross, president, Lockheed Aircraft Corp., stated:

We do not feel that there is a coordinated program in Government and in private industry which is oriented to solve the noise problem. We do not feel that the National Aeronautics and Space Administration is devoting sufficient effort in the area of noise studies which would lead to a solution of our problems.

Donald Douglas, Jr., president, Douglas Aircraft Co., stated:

A program oriented to solve the noise problem has not been coordinated in Government and private industry in the past as well as it might have been. However, natural pressure concerning the problem coming from both the public and those branches of Government and industry most closely associated with such public problems is resulting in better coordination all around and more sincere effort on the part of all concerned to solve those parts of the problem which fall naturally into their own areas of interest. Engine manufacturers working on the development of fan engines and the detailed design of compressor and turbine configurations are making considerable headway in reducing the noise output of jet engines. Aircraft manufacturers are studying and incorporating in their design ways of operating aircraft to minimize the noise. Aircraft operators are making use of these operating procedures and are spending considerable amounts of money to provide ground noise support facilities to keep the noise created by the aircraft during maintenance operations to a minimum.

The NASA has in the past, been very active and has made considerable contributions in the control of noise from jet engines and in the protection of people inside aircraft. Most of this work was done when the organization was known as the NACA. Since reorganization, and with more emphasis placed on space projects, the NASA's efforts in the noise field have been mostly related to sonic boom studies, studies of the noise inside the Mercury capsule, and in the maintenance of a working knowledge of noise problems

in general associated with rockets and missiles. We feel that they should return to the old NACA philosophies about noise and that their efforts in the total field should be considerably expanded.

J. V. Naish, president, Convair Division, General Dynamics Corp., stated:

Yes; we feel there is good coordination in both Government and private industry directed toward solution of aircraft noise problems.

From our viewpoint, the National Aeronautics and Space Administration has contributed significantly to the solution of noise suppression problems. Specifically, the engine noise suppressor which has been developed by the General Electric Co. for the CJ-805 engine was derived basically from a NASA design. In addition, NASA has provided much useful theoretical and analytical work on the basic nature of noise production, in addition to valuable experimental work. It is our opinion that NASA has devoted sufficient effort to keep abreast of the problems in this area.

William M. Allen, president, Boeing Airplane Co., stated:

Certain areas of the noise problem have had the benefit of a coordinated program. For example, the recently published FAA document "Noise Abatement Procedures" was the result of meetings which coordinated the views of airlines, pilots, jet transport manufacturers and Government. In the aircraft noise reduction area, Boeing developed suppressors for jet engines on a company financed, proprietary basis with no Government requirement. However, since the development of these suppressors, Boeing has freely shared its knowledge in this field with both Government and industry.

Basic research in (1) the design of compressors and inlets for turbojet engines, (2) the optimum design trades of helicopter rotor noise, and (3) more intensive collection and distribution of rocket noise survey data should be accomplished by the National Aeronautics and Space Administration. During the past several years, the major orientation of NASA efforts has been almost entirely toward space problems.

William T. Schwendler, chairman of the executive committee, Grumman Aircraft Engineering Corp., stated:

Although there are extensive efforts in organizations such as WADC, NASA, and in private industry, it does not appear to be a truly coordinated program. The more than probable loss in efficiency of design has resulted in little being accomplished in design of engines, aircraft, or missiles with emphasis on noise reduction. At the same time much of the information obtained on noise and vibration suppression seems to be treated as proprietary by many of the firms. It is felt that a more concentrated effort could be placed on reduction of noise levels during ground testing when efficiency is not of prime importance.

It does not appear that problems we are facing in regard to noise suppression or its effect on specific structural designs will be covered by the NASA programs to the extent that we require. In regard to suppression of engine noise, most information has been generated by engine manufacturers. Such methods or devices affect performance and are therefore soon discarded.

J. L. Atwood, president, North American Aviation, Inc., stated:

Yes; there is a coordinated program between the military and its contractors to solve the noise problems pertinent to structural fatigue, crew comfort, and maintenance personnel as well as in-flight operations and the communities adjacent to airports and under the flight path. Specific designs are governed by special design noise level goals. Coordinated effort in terms of research contracts investigating various phases of the noise problem are underway.

The NASA has conducted valuable experiments in the field of acoustics and no doubt will continue in this area. While test programs are proceeding adequately in many fields there is need for additional research in the measurement of aerodynamic noise in flight and for fundamental research on propulsion systems.

A NEED FOR NOISE CRITERIA

General Quesada, Administrator, FAA, stated:

We have made reference to the law, and there is considerable doubt in our mind as to whether the law does place upon us the responsibility of writing and establishing rules for noise-abatement purposes.

Daggett Howard, legal counsel, FAA, stated in testimony before the committee:

On the problem of noise as it was treated when our Agency was established in the Federal Aviation Act of 1958, Congress was not really focusing on the noise problem at that time. They did put into the act the language we have already referred to, the authority to prescribe air traffic rules for the protection of persons and property on the ground.

This latter phrase was a general phrase, however, and in the hearings on this legislation the instances cited as probable areas for the use of this authority were such things as spraying of crops and other uses of airspace, not specifically the noise area.

We, I feel, have stepped up to the plate, if you want to put it that way, in interpreting that literally. That is, interpreting it as a protection of persons and property on the ground even from noise.

I wanted to make that clear because I don't think that even with the act as it now stands, although I consider that a court would rule that it covered noise, that Congress really faced up to the problem of noise.

Now, in another area which has been mentioned here, it is quite clear to me that the power to prescribe noise standards is missing from the act.

The fact that Congress used this phrase "for the protection of persons and property on the ground," only in the air traffic rules section of the act makes it clear that reference is to just safety, air safety or safety in air commerce elsewhere in the act did not extend any further than the traditional previous use of those terms.

I feel, for example, that this question that arose earlier as to whether we could prescribe standards or noise criteria for the performance of engines or aircraft is clearly not covered by the act as it is now written.

I would say that there are good reasons why there should be some such provision in the act.

I might point out that those who are engaged in developing engines and aircraft are competing with each other for performance for an aircraft that will do work and do it efficiently and cheaply. This leads them to build into engines and aircraft maximum performance characteristics without regard to noise.

If there is no general limitation on noise criteria there certainly is no incentive to each developer to adhere to some standards that he may worry about whether his competitor is adhering to, if I make myself clear.

Bernard Shmickrath, engineering manager, Pratt & Whitney Division, United Aircraft Corp., stated:

We recognize as far as the enginework is concerned that we want to, and need to, to improve the noise suppression situation. We recognize that, and we need a set of standards to shoot for to do this. We have put a great deal of effort in it. We don't think that it can be a single group criteria. We don't think it will be accepted. We think it should be an impartial group, using all the various aeronautics people to end up with a situation and a set of criteria, that are acceptable to all.

David Cochran, general manager, flight propulsion laboratory department, General Electric Co., stated in a letter for the record:

There is a definite need for an industrywide standard of measurement. At the present time, acceptability is judged by sound pressure level in db's or phons or perceived noise level in PNdb's. This is further compounded by the fact that even within these systems, different groups use different methods of taking data and calculating results. It is suggested that an unbiased study by an independent group not connected with the engine, the airframe, airport management,

airlines, or governmental regulatory departments be used to establish a criteria for measurement of aircraft noise.

Dr. Hallowell Davis, director, Central Institute for the Deaf, St. Louis, Mo., and former executive secretary of CHABA, stated in a letter for the record:

On the whole the research effort of all three of the medical departments of the Armed Forces has shown commendable ability to stay ahead of the noise problems in the services. For example, the results of the ANEHIN project support this conclusion. Also the Air Force program for the study of noise and vibration control has been broadly conceived, has provided much of the necessary factual data, and should continue to be most valuable. I am not aware of any duplication of effort in this area. The opportunity provided by the Committee on Hearing and Bio-Acoustics (CHABA) for the exchange of information and ideas among scientists from Armed Forces and civilian laboratories has, I believe, helped to prevent unnecessary duplication of effort and has helped each scientist to know better how his work fits into a larger pattern. CHABA should certainly be continued because I believe CHABA should continue to be an important clearinghouse for information and ideas concerning noise problems of all sorts, particularly those of military impact.

However, my general experience of the past 10 years has been that inadequate attention and support has been given to certain long-range research projects which may provide fundamental information on the effects of noise on man and man's reactions to noise. The study of community reactions to aircraft noise is one example. The study of human psychomotor performance in the presence of high intensity noise that is comparable to the noise encountered on the flight deck of carriers or in the vicinity of rocket launchers is another. Systematic monitoring both of the hearing and of psychomotor performance of individuals who work habitually in high intensity noise is a third.

Another problem, which is not so much a matter of obtaining information as of using and applying effectively information that already exists is how to incorporate at the planning and design state of aircraft, missiles, carriers, and airports, the problems of noise and vibration, in relation both to structural and to human factors. In order to avoid serious risks or difficulties in performance it may be necessary to accept certain limitations in design or penalties in regard to weight, space, or cost. But these penalties are far less if the problem is considered early as part of the original specifications of the task. In part the problem of applying existing information exists because the channels of communication from the medical departments to the prime contractors and to those who write procurement specifications are difficult or absent. In part this problem also exists because the medical departments do not have definitive answers to all the questions that should be asked by the writers of specifications. Many answers must still be hedged with qualifications. In order to write such specifications realistically and accurately we require better criteria for permissible noise levels and noise exposures than are now available. The improvement of criteria is thus a long-range and, perhaps, rather expensive type of research which should be carried out but which is likely to be overlooked or indaequately supported.

Dr. Karl D. Kryter, supervisory engineering psychologist, Bolt, Beranek & Newman, Inc., stated before the committee:

There appears to me to be three broad aspects or parts to these human factors problems. Part 1 is that of measuring the inherent response of the average human being to different kinds of sounds. By this, we mean man's response to sounds independently of the meaning those sounds may have for him.

In short, we wish to convert the decibels that Dr. Abbott spoke of into units that have meaning or tell us how people respond to sounds, rather than how the meter that reads in decibels responds to these sounds.

Part 2 of this general problem is to measure the feelings people have about aircraft noise because the noise bothers them or disturbs them.

This, of course, is a more complicated part of the problem than the first part.

Part 3 I think is the establishment of criteria of tolerability of acceptability: that is to say, how much, how often, and when people can justifiably be exposed to intense aircraft noise.

Dr. Richard Bolt, Associate Director (Research), National Science Foundation, in his prepared statement said:

In any case, establishment of criteria is the first stage in the rational analysis of any noise problem. Next, one must analyze the sources of the noise—the various points at which mechanical vibrations, airflow, impact of metal parts, and so forth, generate the noise. This is largely a matter of acoustical engineering, in some cases today quite routine, but perhaps with a strong assist from mathematics, physics, mechanical engineering, aeronautical engineering, or other fields.

The third general stage of noise analysis is to determine the many paths along which noise "flows" from the sources to the receivers of the noise, be they people or equipment. Usually there are many such paths. It is not enough to close the front windows if noise is still coming in the rear windows. It is not enough to muffle the exhaust stack of an aircraft engine test cell if appreciable noise is leaking through cracks and doors. This phase of the problem—the calculation of all the paths and their relative contributions—often turns out to be a large-scale sleuthing job, tracking down the many ways in which sound energy can escape and intrude. But the underlying principles are reasonably well understood, and the well-equipped acoustical engineer knows how to tackle the problem.

The final stage of noise control is synthesis: bringing together all the information regarding the sources, the paths, the receivers, and the criteria that specify what noise is "acceptable"—and then designing a suitable solution. It must be suitable in many ways: it must produce an acceptable situation for those on whom the noise is impinging, and it must also be an operationally and economically feasible solution.

The synthesis of a suitable solution is greatly aided by the concept of the noise system. As outlined in the accompanying diagram, this system represents the flow of noise energy from sources, through paths, to receivers, and the measurement of receiver responses by an indicator ("meter") that can be checked against the applicable criteria.

The system diagram for an actual problem usually contains many blocks, to represent several sources, paths, and receivers, joined by a complicated network of interconnections. Each block is assigned appropriate numbers (in watts, decibels, cycles per second, and so forth) and the performance of the entire system is calculated.

Then the engineer is in a position to propose possible solutions and predict their consequences. Each proposed solution is represented by a set of adjustments of different parts of the system.

Consider, for example, the following problem. Noise from aircraft operations on and near an airport gives rise to widespread complaints from a nearby community in the town. A possible solution might call for the adoption of three noise control measures:

(1) Require the aircraft to carry a muffler of specified performance (a source adjustment);

(2) Alter the flight patterns to increase the average distance between flying aircraft and the community (a path adjustment);

(3) Inform the community that measures are being taken to reduce the noise per se, that the airport brings valuable new business to the town, and so forth, as appropriate (a receiver adjustment).

Many aircraft noise problems are too severe to be solved by any one "adjustment." The noise from a present type turbojet engine, for example, cannot be "muffled" by more than a few decibels without incurring a large penalty in performance. Each part of the system must carry a reasonable portion of the noise control.

The several interests—manufacturers and operators of aircraft equipment, airport planners and operators, and the residents of noise-exposed communities—must work together toward sharing the burden equitably. The engineering techniques needed to guide such cooperative efforts are now available through the analysis of the noise system, along the lines indicated above.

VII. Conclusions

As a result of a careful study of the testimony given during the hearings, letters from knowledgeable persons contained in the appendix to the hearings, and a preliminary staff investigation, the following conclusions are drawn:

(1) A great deal of noise research is underway in the Government, but there appears to be a lack of common orientation except in the armed services through the Armed Forces—National Research Council Committee on Hearing and Bio-Acoustics (CHABA).

(2) Although NASA and FAA are participating members of CHABA, they have not, in the past, taken full advantage of this outstanding Committee to assist them in orienting their respective programs.

(3) The NASA noise research program has been level budgeted for the past several years and, according to testimony before this committee, will continue as a level effort, although noise problems are more acute than ever before. NASA appears to have reoriented its noise research program toward investigating the noise problems of manned space flight, the sonic boom phenomenon and the supersonic transport at the expense of solving today's aircraft and rocket noise problems.

(4) More research and development effort is necessary and additional research tools are needed, before a set of noise criteria can be drafted, around which industry can design aeronautical and space flight vehicles.

(5) There is no impartial, highly qualified Government group specifically charged with the responsibility for formulating noise criteria.

(6) Even if a set of noise criteria was established, satisfactory to industry, the public and the Government, it is questionable if the FAA has under the present law the regulatory authority to enforce it.

(7) Both the Government and industry recognize their responsibility to the public to consider noise abatement in the design of aircraft, aircraft engines, rockets, and missiles. The research effort that has been going on for the past few years should shortly be evident to the public with the introduction of the turbofan engine for airline use. Increased aircraft performance should allow steeper climb angles out of the airports.

(8) The sonic boom phenomenon must be more clearly understood and recognized as a serious problem in the operation of supersonic air transports. The FAA is already concerning itself with this problem during all stages of the design of this vehicle.

(9) As the speed of aircraft increases, the problems of sonic fatigue become more serious.

(10) Boundary layer noise will possibly complicate the communication problem for the astronaut during lift off and exit from the atmosphere and during reentry.

(11) Testimony by the eminent witnesses heard by the committee reveals that research and development directed at eliminating noise at the source cannot provide the entire answer to noise abatement. The noise problem must be attacked utilizing a system approach. Included are:

(*a*) Better aircraft, missile, and rocket design.
(*b*) Better engine design.
(*c*) Better airport planning.

(*d*) A new approach to zoning around airports.
(*e*) Revised air traffic procedures.
(*f*) Public education.

Last but not least, all of the avenues listed above must first be approached using a set of agreed upon criteria or standards.

VIII. Recommendations

It is recognized that the public aspects of the noise problem are of considerable concern; however, until basic scientific definitions and tools become available, no lasting progress can be made in easing the current noise problems. Therefore, the following recommendations are directed toward the scientific aspects in research and development:

(1) That a set of criteria be developed by a single, impartial, Government agency which does not have any regulatory responsibilities. It is suggested that the Armed Forces—National Research Council Committee on Hearing and Bio-Acoustics is the ideal group to undertake such a project, since all interested Government agencies have an affiliation with this committee. In addition, the CHABA has the respect of industry and the scientific community.

(2) That NASA increase its emphasis on noise research, particularly in reemphasizing research in solving the noise problems of today's jet airliners.

(3) That noise criteria be mandatory requirements in the drafting of specifications for future military and civil aircraft, rockets, and missiles, consistent with the necessity for military performance.

(4) That basic research and development effort into the effects of noise on man and machine be increased commensurate with the recognized seriousness of the problem.

(5) That closer cooperation and exchange of technical data, through CHABA, be implemented by industry and the scientific community.

(6) That Congress amend the Federal Aviation Act so that it clearly delineates FAA responsibility for fostering research and development relevant to noise control planning for civil aviation.

(7) That the National Science Foundation encourage more basic research in investigating the anatomy of noise. Research grants should be increased to emphasize the importance of the need to study the psychological and sociological unknowns abounding in the subject of noise and its effect on man.

(8) That NASA become a full member-partner with the three armed services, and the FAA in providing funding support to CHABA instead of remaining an affiliate member of the Committee. In addition, NASA should rely on CHABA for noise program orientation.

(9) That all so-called informal Government cooperation be formalized and channeled through CHABA.

(10) That formal Federal Government, local government and industry symposia be planned under the sponsorship of CHABA as an initial step toward planning a nationwide attack on the noise problem.

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